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A PROPOSAL TO SEARCH FOR SHORT-LIVED PARTICLES PRODUCED BY ANTINEUTRINOS AND NEUTRINOS

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22pgs.

TABLE OF CONTENTS

APPENDICES

in antineutrino data of a "high-y" anomaly and an increase in $\sigma(\bar{\nu})/\sigma(\nu)$ at higher energies. The study of $\bar{\nu}$ events in nuclear emulsion for $E_{\bar{\nu}} > 60$ GeV should enable us to separate the decay vertex from the production vertex in individual eventsand thus to isolate and study the decays of these higher mass states if they exist.

C. DESCRIPTION OF THE EXPERIMENT

The experiment consists of an emulsion target irradiated by a beam of antineutrinos and neutrinos, followed by a downstream spectrometer/cascade shower detector. A plan view of the apparatus is shown in Figure 2. A 15 liter nuclear emulsion target located at the upstream edge of the magnetic field serves as a track sensitive target with spatial resolution in the submicron range. The extremely short-lived particles being sought are identified by the observation of a decay vertex spatially separate from the production vertex for the event in question. The downstream spectrometer/shower detector provides a crude determination of the energy in the hadronic shower and some momentum information on individual tracks as well. In particular, the muon produced in a charged current event is identified, and its sign is determined, in this part of the apparatus. The magnetic field volume is 2.4m x 1.5m x 0.6m and the field in the central part of the magnet is 8kg.

(The poleface area is 2.4 x 1.5 m^2 and the poles are 0.6m apart). The emulsion target is divided into two planes, each consisting of an array of removable target subassemblies described in sections C2 and C3 below. A flashtube chamber[6] is placed immediately downstream of each emulsion plane. More flashtube chambers are placed in the magnet gap and further modules serve as the active elements of the shower detector. The spatial resolution of the flashtube chambers is sufficient to allow momentum determination to an accuracy

C1. Event Rates, Background, Total Protons on Target

We assume there are two planes, each an 8 x 45 array of 2 inch (diameter) cylinders of emulsion. The emulsion thickness is 1cm in the beam direction. The total amount of emulsion physically in the target is 14.6 liters. If a 3 mm border around the outer rim of each cylindrical target is not analyzed (to avoid problems with distortion) we have an effective target volume of 12.9 liters.

We have taken as our primary goal the achievement of 10 $\bar{\nu}$ charged current and 4 $\bar{\nu}$ neutral current events having $E_\nu \geq 60$ GeV. The number of 400 GeV protons on the target needed to accomplish this goal depends on the type of neutrino beam used.

The flux curves used were those of Stefanski and White (FN-292)*. To convert these numbers into units useful for our purposes, the fluxes were weighted by the cross section which was assumed to be $0.74 \times 10^{-38} E_\nu$ (GeV)cm^2 for neutrinos[10] and one half this for antineutrinos[11] (this over estimates the low energy $\bar{\nu}$ events by $\sim$ 25%). We could then plot the calculated fluxes as an event rate/liter of emulsion/10^{18} protons. This is done for various beams in Figure 3 . The curves shown are integral curves, i.e., total events above $E \geqq E_{min}$.

As a check we used these curves to estimate the expected rate in E247 which received 1×10^{18} protons and had a target of 18.6 liters of nuclear emulsion. The beam used was the double horn.

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*Beams used in this calculation, in the numbering scheme of Stefanski and White in FN-292:

Bare target	$\bar{\nu}$: 7	
Double Horn	$\bar{\nu}$: 19	ν: 18
Triplet	$\bar{\nu}$: 37	ν: 36

TABLE C1.I

Beam	Total Event Rate* (at 15' BC)	E >60GeV
1. Double Horn		
ν	127.6	46.0
$\bar{\nu}$	30.7	5.3
2. Bare Target		
$\bar{\nu}$	7.0	1.8
3. Triplet		
ν	30.2	21.4
$\bar{\nu}$	3.82	2.09

*per 10^{18} protons in 12.9 liters of emulsion

TABLE C1.II

Beam	Required Number of 400 GeV Protons† For 10 $\bar{\nu}$ Events ($E_{\bar{\nu}} \geq 60$ GeV)
1. Double Horn	3.7×10^{18}
2. Bare Target	11×10^{18}
3. Triplet	9×10^{18}

†After geometric and tagging efficiency corrections

TABLE C2.I

Detector	Resolution	Purpose
Flash Tubes	$\leq$ 1cm	Reject non-emulsion triggers Choose cylinder to be removed
"Holey" Spark Chambers	<200μm	Find search areas for glass plates coated with emulsion
Double-Sided Emulsion-Coated Glass	< 2μm	Find $\geq$ 2 tracks for extrapolation to the event

TABLE C3.I

Typical Shower Multiplicities for Electrons and Photons

Emulsion thickness:	1.5 cm		3.0 cm	
500 MeV Electron in;	0	6%	0	15%
	1	85%	1	65%
> 50 MeV Electron out	>1	9%	>1	20%
500 MeV Photon in;	0	70%	0	50%
> 10 MeV Electron out	1	3%	1	7%
	>1	27%	>1	43%

(Numbers are taken from electron-photon shower distribution - Messel and Crawford -- the tables for copper were used).

(see below) will be located on both sides of the glass plate. About 20 grains will be visible on each side. Use of the two-sided glass plate permits measurements of track angles to about ±3 mrad -- ample accuracy if two or more tracks are found, for extrapolation to the event in the target stack. Monte Carlo studies have shown that cosmic ray tracks in these plates will not be a problem.

Relative positions of the glass plate and the target pellicles can be found within a few microns by x-raying the stack using a collimator with a fine hole. The technique for doing this has been tested satisfactorily by the Lund group (See Appendix II). Muon beam tracks will be used for the final alignment of the stack.

Following the glass plate is another glass plate coated with evaporated gold, a 1cm gap and a second gold-flashed glass plate. The two plates form the electrodes of a small spark chamber which is pulsed for each event trigger. Provided the spark chamber is properly designed, constructed and electrically pulsed, it will not break down without a track in it. The trigger rate, if similar to E247, will be ∿ 10-20 x the actual event rate, so we can expect ∿ a few tracks/trigger, spread over the whole apparatus.

Tracks causing a spark will make small holes in the gold coating of the plates. A short test (with aluminum coating) revealed that the mean hole diameter was 200 microns with a tail extending to 700-800 microns Further development work might reduce the diameter of the holes and is under way in the M5 test beam. The background of holes from other triggers will not be serious. The hole diameter corresponds roughly to the field of view of the microscope, so by aligning the two plates under the microscope it should not be difficult to find the track of interest. A test of this will be carried out soon in the M5 beam (see Figure 4).

SUMMARY OF SECTION C3: DESIGN CONSIDERATIONS FOR EMULSION STACKS

1) Why are there removable target modules? This gives us immediate feedback during the run, reduces the average cosmic ray background and, with the right stack volume avoids having to develop all of the emulsion. We gain most if the number of events is small. With 75 tagged events 20 cm^3/event means that only 10% of the target needs processing.

2) Why is the thickness of the stack 1 cm? The reasons for this are given above. We feel that the use of thin emulsion stacks is a distinguishing characteristic of this experiment from other proposed or approved experiments.

3) Why 20 cm^2 area? This is a reasonable compromise between edge losses due to distortion and low stack volume/event.

4) Why the choice of a vertical exposure? We are still examining whether a horizontal exposure would be possible without significant increase in wasted emulsion due to edge effects. A 3 mm edge means 60% waste for a 1cm thick horizontal stack and 10% for a 1cm vertical stack. Also the module design is simplified using the vertical exposure. The problem of following tracks in a vertical exposure is removed by using reference muon tracks. Some problems remain, however, which are discussed in Section C4 below.

angular distribution of the heavy meson, while the same measurement in the xz or yz planes is a Lorentz invariant and depends only on $c\tau$. For this reason alone we would choose horizontal exposure, but since all other factors indicate the use of vertical exposure more thought is needed and this remains an unsolved problem, unless we assume large $p_\perp$ production of heavy mesons. Both horizontal and vertical geometries will be tested with pion events in the M5 beam.

The energy and directional resolution of a prototype flashtube chamber calorimeter will be studied in the M5 test beam in May, but some estimates can be made using the work of Gabriel and Schmidt (ORNL/TM 5105, 1976). They show that when appropriate fluctuation correlation corrections are made, the energy resolution depends mainly on the total module thickness (iron plus scintillator). Using their Figure 5 we would expect DE/E = 200 percent/$\sqrt{E}$ (FWHMO with our 40 gms/cm^2 modules. They also indicate a directional accuracy of 100 Mrad (FWHM) for particles detected via the hadronic showers only, and state that considerable improvement is achieved when the particle is tracked into the chamber, or when its origin is known.

The characteristics of the entire graded calorimeter are given in Table C6.II, and details of a module from the hadron region are shown in Figure *. The slabs of scintillators occur in only 2 of the 20 modules, selected to be at the average shower maximum. This allows us to trigger the flashtubes and minispark chambers on events with total hadronic shower energy greater than several GeV.

In addition to identifying and measuring the energy of photons and electrons, in the early thin plate part of the calorimeter, we will also have some identification capability via range for low energy particles. For example, a 600 MeV/c proton just stops in 10 inches of aluminum, and 1.5 GeV/c muons stop deep in the hadronic region of the calorimeter.

*This figure was omitted in the final preparation of this proposal.

553

D. PERSONNEL, COST OF THE EXPERIMENT

Personnel:

Cornell

E. M. Friedlander

L. N. Hand

P. Karchin

H. Weiner

\+ one more research associate

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B. Andersson

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Pittsburgh

W. E. Cleland

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E. Engels, Jr.

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R. Holynski*

A. Jurak

S. Krzywdzinski*

G. Nowak

H. Wilczynski

W. Wolter*

\+ 4 full-time scanners

York (Canada)

W. R. Frisken

*These physicists have additional research commitments

<u>Division of Costs</u> (Letters below refer to items above)

1. National Science Foundation (Cornell/Pitt)		
a, d, e, f, l, n, 1/2 of m	100 K*	
2. Swedish National Research Council (Lund)		
b, c	15 K	
3. National Research Council of Canada and Canadian Institute of Particle Physics (York)		
i, j, 1/2 of m	36K	
4. Fermilab Support		
o, p, q	165K	
Total Cost of the Experiment		$ 316 K

Operating costs, travel costs, and analyzing costs are not included in the above. Most of these latter costs are covered under existing grants.

Funds to support the Krakow and Lund scientists in the U.S. and to pay for their travel from Poland and Sweden, will be requested from the NSF.

*Approximate new funds to be requested, not including overhead salaries, etc.

553

E. TIME SCALE OF THE EXPERIMENT, DIVISION OF RESPONSIBILITIES; ADDITIONAL COLLABORATORS

July 1, 1977	Approved by PAC and Laboratory
October 1, 1977	Agreement signed Cornell magnet available
November 15, 1977	Cornell magnet arrives at Fermilab, installation begins
December 1, 1977	Emulsion target production starts. Installation of calorimeter and target begins.
March 1, 1978	Data run begins
July 1, 1978	Data run ends
July 1, 1979	Data analysis completed

Division of Responsibilities on the Experiment

Cornell (LNS)	Loan of magnet to Fermilab; moving of magnet
Cornell/Pitt/York	Emulsion target, target flash tubes, glass spectrometer
Pitt/York	Flash tube hadron calorimeter, scintillation counters, optics, photographic equipment
Cornell/Lund/Krakow	Emulsion target fabrication, x-ray marking, event searching, event reconstruction
Lund	Emulsion processing
All	Data analysis

Additional collaborators from Fermilab would be welcome.

$$\Delta'_{ij} \equiv (x_{ij}-x_o)\sin\psi_j - (y_{ij} - y_o)\cos\psi_i \qquad (2)$$

are calculated for all grains.

The test criterion will be

$$H^2 \equiv \sum_{j=1}^{m} \sum_{i=1}^{n_j} \frac{\Delta'^2_{ij}}{\sigma^2} \qquad (3)$$

where σ is the r.m.s. deviation of estimated grain centers about the true particle trajectory. (In K-5 emulsion 0.06 μm < σ < 0.07, reading errors included).

Now once (x_o, y_o) represents only a pseudo-vertex the Δ'_{ij} will differ from the "true" deviations Δ_{ij}

$$\Delta'_{ij} = \Delta_{ij} + \lambda_j \qquad (4)$$

where λ_j is the offset at the origin of track j. (Trajectories passing through the vertex have obviously $\lambda_j = 0$).

3) The whole clogged region is now scanned ($x_o y_o$ are varied in steps as small as 0.01μm) and a minimum is sought for H^2. Since by virtue of the least squares procedure

$$\sum_{i=1}^{n_j} \Delta_{ij} = 0 \qquad (5)$$

it follows that

$$H^2 = X^2 + \frac{1}{\sigma^2} \sum_j \lambda_j^2 n_j = X^2 + T^2 \qquad (6)$$

where $$X^2 \equiv \Sigma \Delta^2_{ij}/\sigma^2 \qquad (3')$$

In all cases the track quartet not including the track with $\lambda \neq 0$ had f_{min} obeying the same distribution as for the case $\lambda = 0$, while all other combinations had large f_{min}- values. For $\lambda = 0.1$ µm, 63% of all f_{min} were >3. For $\lambda \geq 0.2$, all $f_{min} > 3$. It is obvious that detection of offsets $\lambda \geq 0.2$ presents no difficulties at all, and a sizable fraction of cases with λ as low as 0.1 are detected, too.

In order to gain an idea about the sensitivity of the method to spontaneous particle decay, we consider the case of two body decay of a neutral short-lived particle. Then, generally speaking, two tracks will have $\lambda_j \neq 0$. Let ℓ be the projected flight path and θ_j the projected emission angles of the decay secondaries (measured from this flight path). Then the second term in eq. (6) becomes

$$T^2 = \frac{\ell^2}{\sigma^2} \sum_{j=1}^{2} \sin^2\theta_j n_j \quad (8)$$

The significance of T^2 is different for "horizontal" and "vertical" exposures (neutrinos incident along the plane of the emulsion or perpendicular to it).

In the "horizontal" case* it can be shown that

$$<T^2> \sim \frac{n}{3} \left(\frac{cT_0}{\sigma}\right)^2 \quad (9)$$

where T_0 is the mean lifetime of the decaying object and $n_1 = n_2 \equiv n$ has been assumed. This is independent of the momentum P of the decaying object since Lorentz dilation of ℓ is canceled by the Lorentz narrowing of emission angles.**
For isotropic decays $T^2 < <T^2>$ in 58% of the events.

*The effects λ_j are determined by the decay angles θ_j

**Hence neither production nor decay kinematics affect $<T^2>$

With concrete numbers $c\tau_0$ turns out to be of the order of 0.1μm, or τ_0 3.10^{-16}.

Once a "negative" test result*) has been obtained, the tracks are split into two groups in all possible ways until two vertices (two "X^2-holes") emerge. The decay path is then estimated from the distance between the points at which H^2 reaches its minimum for each group of tracks.

Technically, all depends on keeping σ at the "sub-(0.1μm)" level. The main obstacles in the path of such a measurement are strange noises and, above all, thermal noises, connected with different dilatation coefficients of parts of the measuring system. Intermediate microphotographs have been shown to be free of these spurious effects to a large extent.

The large amount of measurements involved, especially in the case of a "vertical" exposure can be handled efficiently only with a computer controlled, digitized, semiautomatic microscope. Such a device is in construction at Cornell University under an NSF grant.

*) Of the zero hypothesis that there <u>is</u> a single vertex

Appendix III

References to Previous Publications by Others Relevant to This Proposal

1. Tagged Nuclear Emulsion Experiments

With Neutrinos:

a) E.H.S. Burhop et al., Nuovo Cim. 39 (1965) 1037

b) E.H.S. Burhop et al., Physics Letters 65B, 299 (1976)

Other:

a) Dayon, M., *JETP* 37 4, 906 (1959)

b) Proceedings of the 9th Int. Conf. on Cosmic Rays V2, 827 (1965)
K. Pinkau et al., p. 821; Yu Smorodin et al, p. 827; N.L. Grigorov, p. 851

For later work see Golden et al., ref. Appendix III and numerous other articles.

2. "Holey" Spark Chambers

a) L. Hand, Neutrino Workshop, April 22, 1977

b) J. Fischer and G. Zorn, pg. 281, Proc. of an Int. Conf. on Instr. for High-Energy Physics, LRL 1960

c) See also A. A. Tyapkin, pg. 270, Berkeley Conf. 1960, for a useful discussion

References c. and b. were supplied to us by Dr. L. Voyvodic of FNAL.

3. Glass Plate Spectrometer

a) A. J. Apostolakis and I. Macpherson, Proceedings of the Physical Soceity, A, vLXX, 146 (1957) and 154 (1957)

b) L. Alvarez, et al., Sixth International Conference on Corpuscular Photography, 1966

c) R. L. Golden, et al., *Nucl. Instr. and Methods* 113, 349 (1973); plus NASA reports.

d) J. J. Lord, et al., 6th. Int. Conf. on Corpuscular Photography, p. 387 (1966).

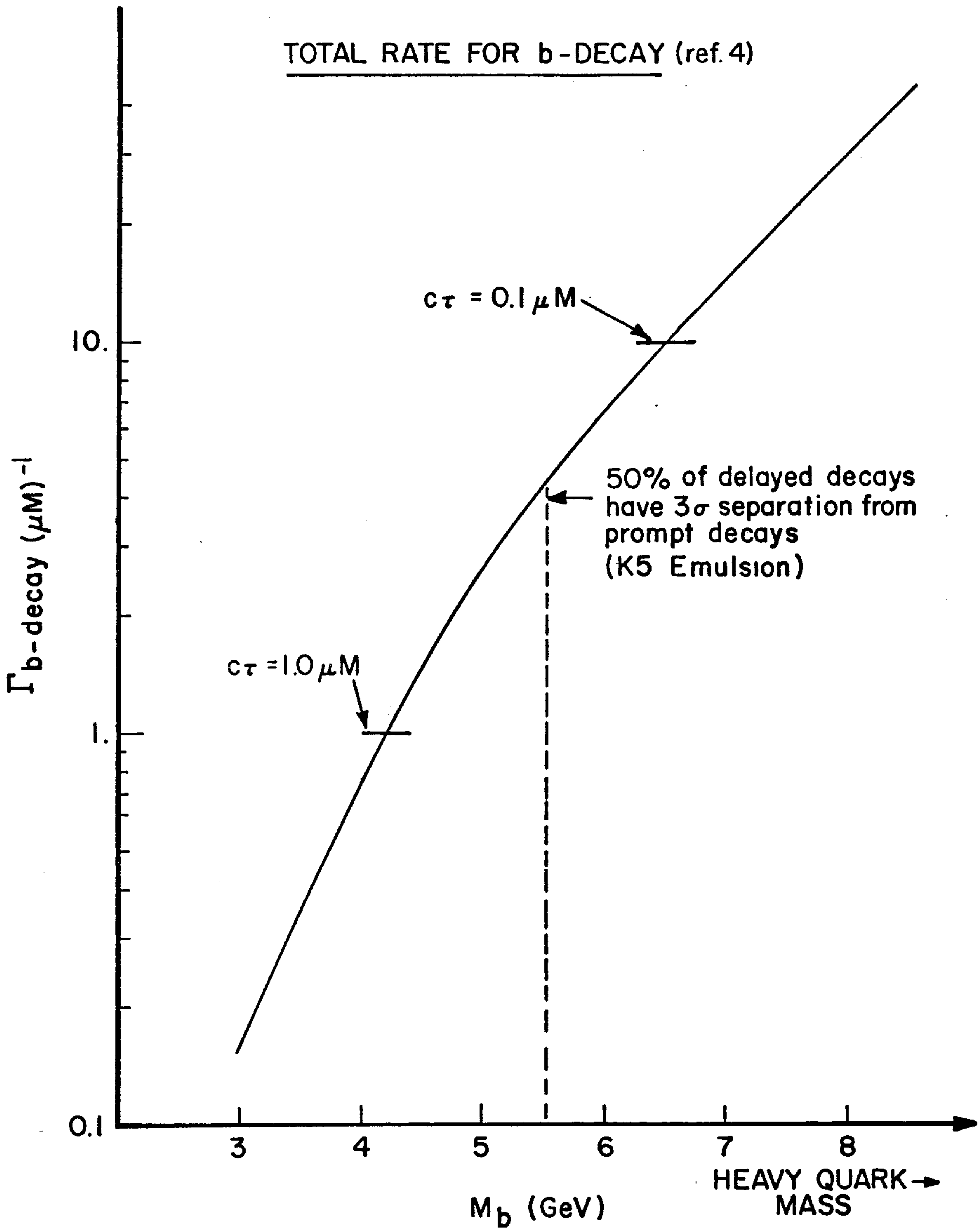

TOTAL RATE FOR b-DECAY (ref. 4)
$c\tau$ = 0.1 μM
$c\tau$ = 1.0 μM
50% of delayed decays have 3σ separation from prompt decays (K5 Emulsion)
$\Gamma_{b\text{-decay}}$ (μM)$^{-1}$
10.
1.
0.1
3
4
5
6
7
8
HEAVY QUARK MASS
M_b (GeV)

Fig. 1

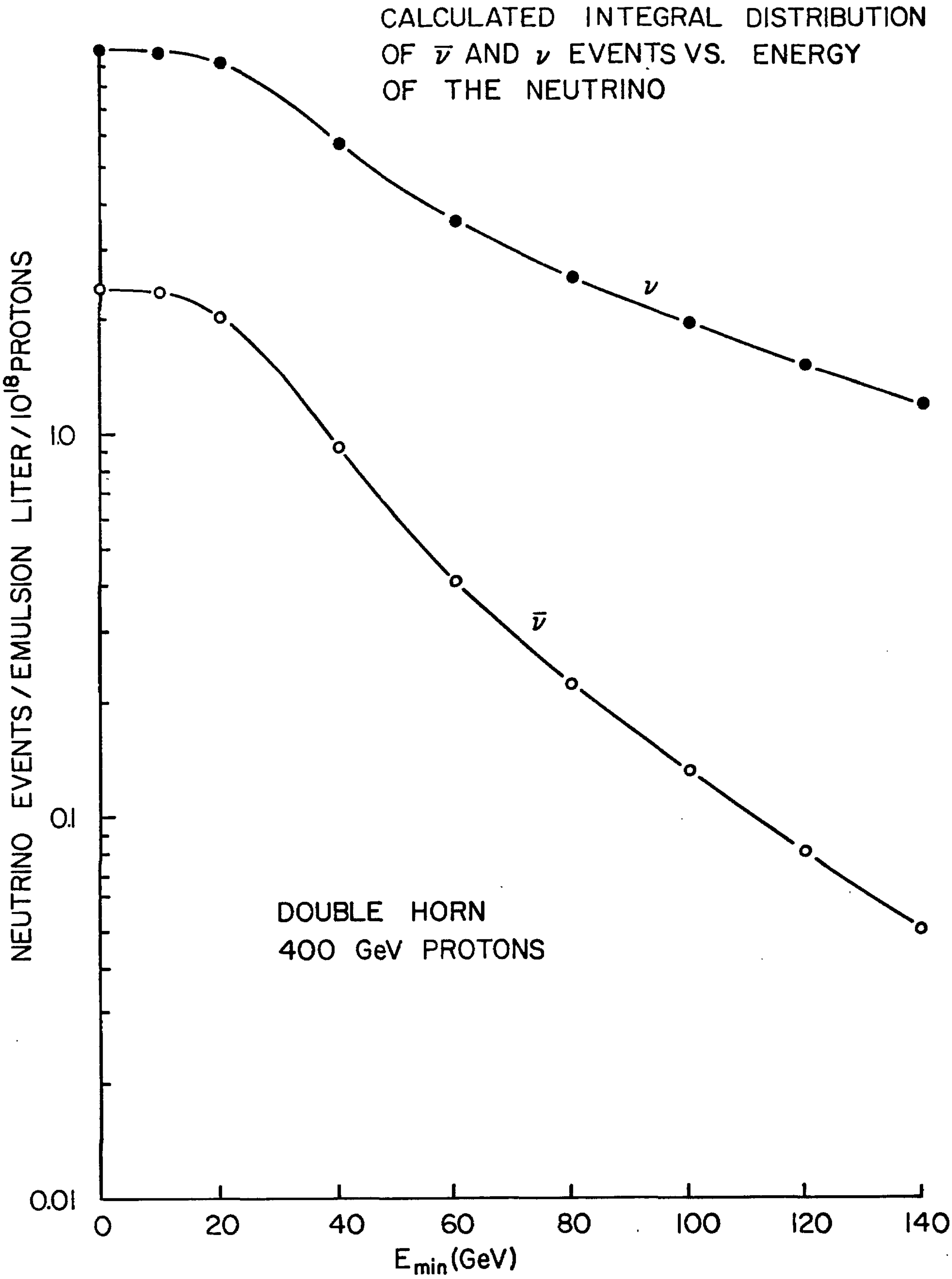
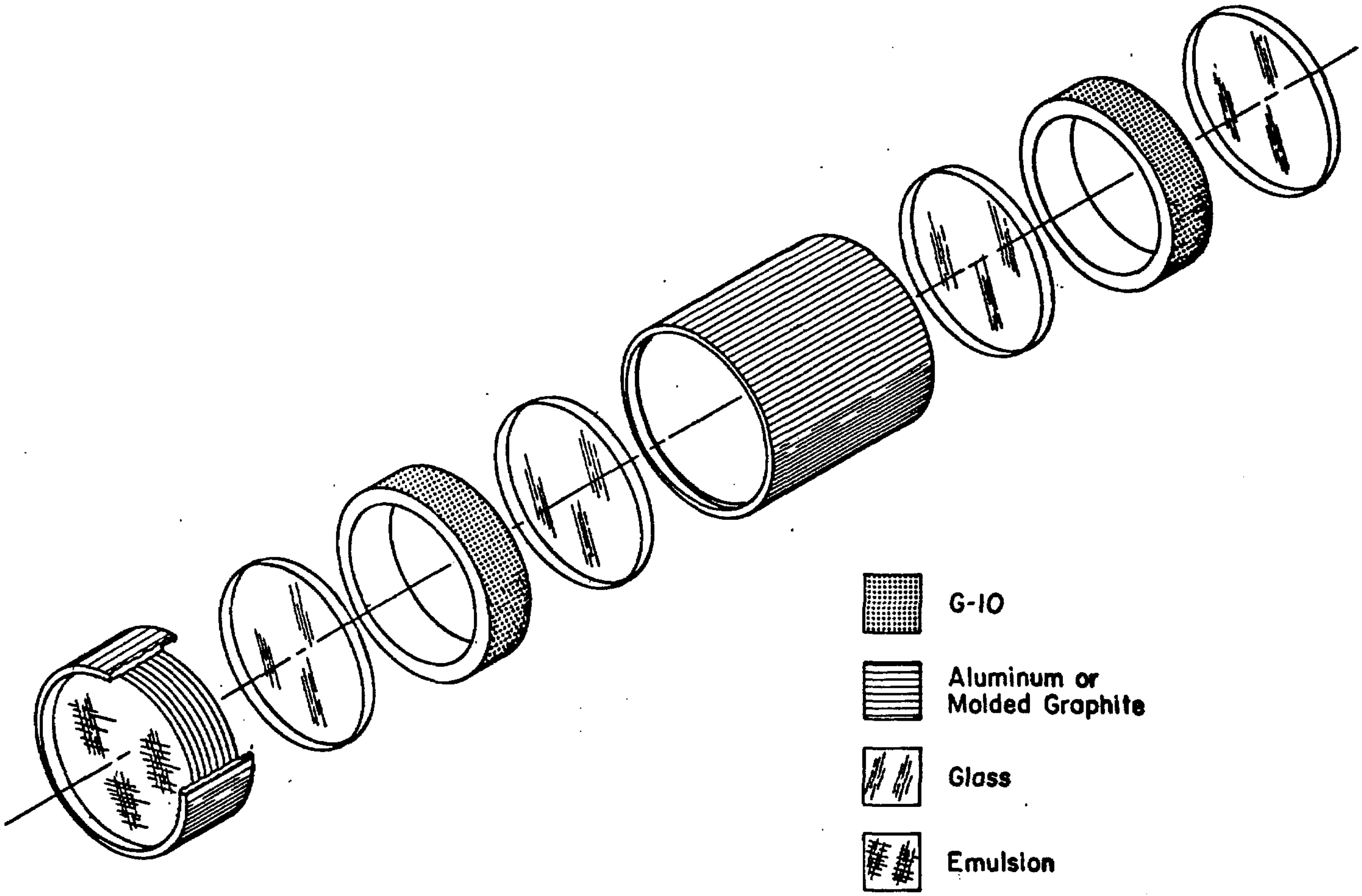

CALCULATED INTEGRAL DISTRIBUTION OF $\bar{\nu}$ AND ν EVENTS VS. ENERGY OF THE NEUTRINO
NEUTRINO EVENTS / EMULSION LITER / 10^{18} PROTONS
1.0
0.1
0.01
ν
$\bar{\nu}$
DOUBLE HORN
400 GeV PROTONS
0
20
40
60
80
100
120
140
E_{min} (GeV)

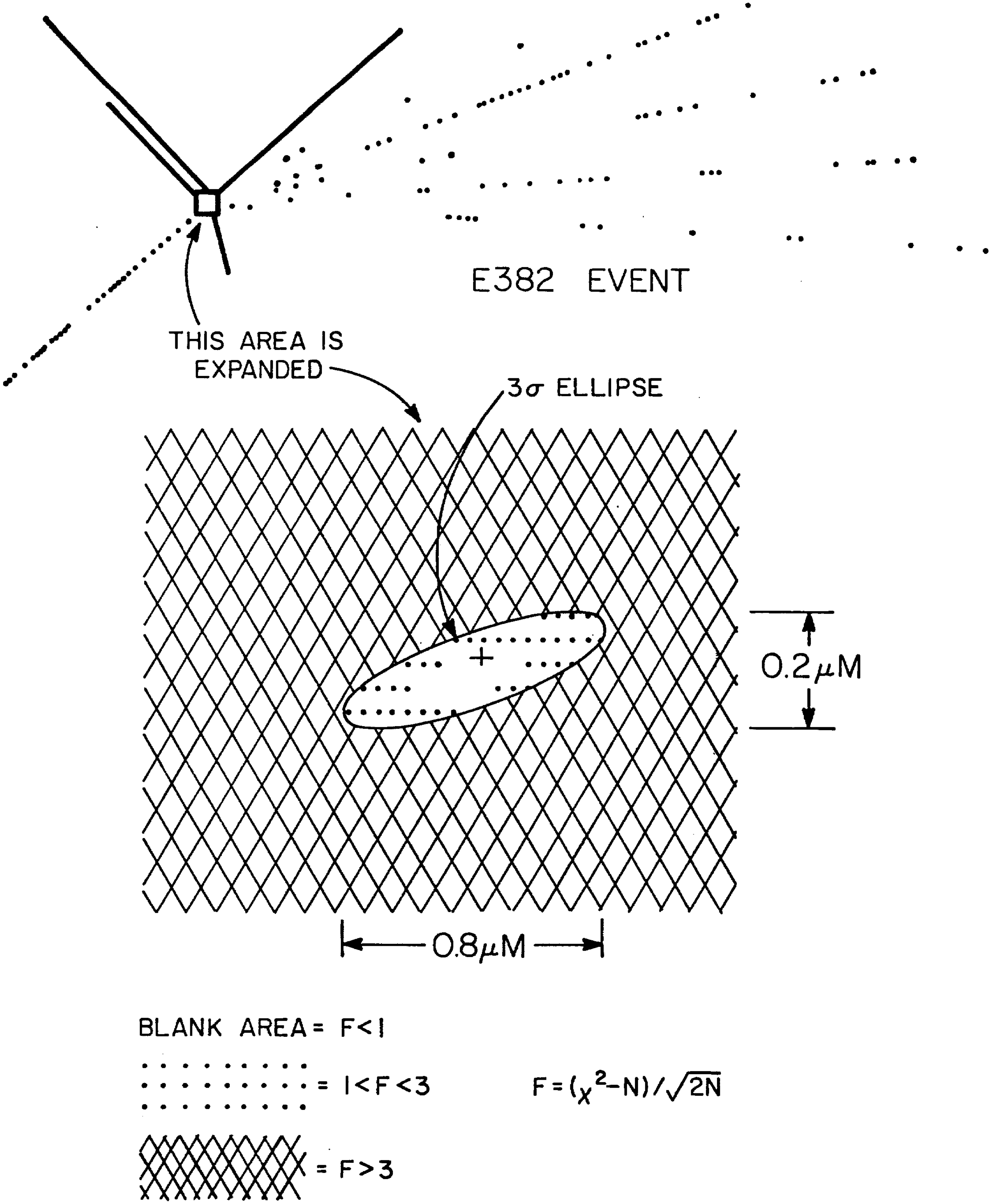
Fig. 3



Length ~10cm assembled

POSSIBLE TARGET MODULE DESIGN

Fig. 5



SEARCH FOR DELAYED DECAYS AT STAR VERTEX IN E382

Fig. 7