INFORMATION CONCERNING NEUTRINO CONFIGURATIONS AND FLUX: CONSEQUENCES FOR NEUTRINO-PHYSICS EXPERIMENTS

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ABSTRACT

The current neutrino-physics proposals are considered with a view to estimating how seriously the event rate is reduced by an earth neutrino shield instead of a steel neutrino shield. A similar comparison made for the individual physics topics contained in the proposals. As a background, information concerning the cost of uniform or composite neutrino shields is compiled together with flux estimates for some of the configurations.

I. NEUTRINO SHIELD

Table I presents neutrino-shield lengths (range +20%), assuming collision loss only, for a number of materials, steel, heavy concrete (iron ore + cement), compacted iron ore, and compacted earth. The range data were taken from NAL report TM-229[1] together with more recent information.[2] The cost estimates were obtained from a number of different sources.[3] A 400-GeV steel shield costs in excess of 10^7 dollars. None of the other materials except compacted earth offer substantial cost reductions. The cost, of course,

Table I. Neutrino-Shield Lengths (Range +20%) and Cost.

Material	100 GeV	200GeV	300GeV	400GeV	500 GeV
Steel length (ρ = 7.85)	75	148	214	284	348
Cross-section size	5×5 m	5×5 m	6×6 m	7×7 m	7×7 m
Cost at $100 per ton	1.6×10^6	3.2×10^6	6.7×10^6	12×10^6	15×10^6
Iron ore + cement (ρ = 4.4) length	128	248	353	481	598
Cross-section size	7×7 m	7×7	8.5×8.5	10×10	10×10
Cost at $50 per ton	1.4×10^6	2.8×10^6	5.8×10^6	11×10^6	13.7×10^6
Iron ore compacted (ρ = 3.5) length	161	312	444	615	752
Cross-section size	8×8 m	8×8	9×9	11×11	11×11
Cost at $30 per ton	0.9×10^6	1.8×10^6	3.2×10^6	6.3×10^6	7.8×10^6
Earth compacted (ρ = 2.0) length	241	501	740	1080	1210
Cross-section size	10×10 m	10×10	12×12	14×14	14×14
Cost at $2 per ton	0.05×10^6	0.1×10^6	0.2×10^6	0.4×10^6	0.5×10^6

depends on the cross-sectional size assumed and current estimates[4] may change with more refined calculations.

II. NEUTRINO FLUX

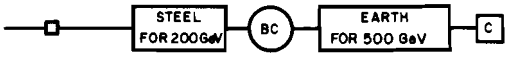
Figure 1 shows the neutrino flux for different decay lengths (D) and different neutrino-shield lengths (S).[5] There are substantial improvements in the low-energy flux for short shield lengths, while the high energy flux is largely insensitive to changes in shield and decay lengths. For this reason, a steel shield is desired. Curve A of Fig. 1 comes close to representing the flux for a steel neutrino shield, and curve B is close to representing the flux for an earth neutrino shield. There is a difference of about a factor of ten between curves A and B for the flux in the region 5-15 GeV. Figure 2 shows the neutrino flux as a function of targeting energy for the region 100-500 GeV.[5]

III. AREA I NEUTRINO-SHIELD CONFIGURATIONS

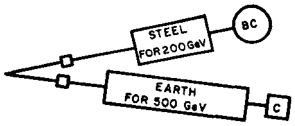
In addition to the uniform neutrino shield usually considered, there are a number of other neutrino-shield configurations possible: some are sketched below.

A. Uniform shield (possibly composite)--one target, one detector location

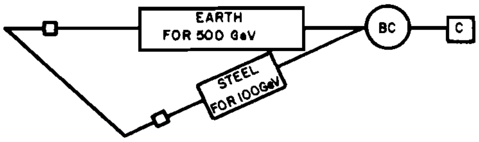
B. Two shields in line--one target, two detector locations



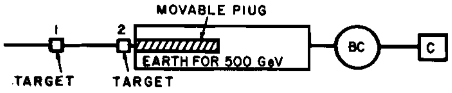
C. Two shields, two targets, two detector locations



D. Two shields, two targets, one detector location



E. Maschke suggestion--one shield, two targets, one detector location



F. Sculli suggestion--two shields, two targets, two detector locations, similar to configuration C, except additional beams (μ, diffracted proton) come off the second target to serve counters or a bubble chamber.

IV. ECONOMICS OF A COMPOSITE NEUTRINO SHIELD, EARTH AND STEEL FOR 400 GeV: ALTERNATIVE SUGGESTION

Table II explores the characteristics of a composite neutrino shield of earth and steel in a number of different proportions. What is envisioned in this configuration is to have the earth at the beginning of the shield facing the target and to have the steel at the rear of the shield next to the detectors. A composite shield with a total length of ~640 meters (180 steel) as shown in Table II would yield a neutrino flux similar to curve C of Fig. 1 which has values intermediate to curves A and B. Such a shield would cost ~5×10^6 dollars. With such a composite shield, the possibility exists for the earth to be replaced with steel so that the shield length can be shortened, thereby enhancing the low-energy neutrino flux somewhat. However, the cost of this configuration is still rather large and depends on the cross-sectional size assumed.[4]

Table II. Neutrino Shield (400 GeV)--Composite Earth and Steel.

Earth Length (m)	Steel Length(m)	Total Shield Length (m)	Cost in $
1080	0	1080	0.5×10^6
841	75 (5×5 m)	916	1.7×10^6
581	148 (5×5 m)	739	3.3×10^6
460	180 (5.5×5.5 m)	640	5×10^6
340	214 (6×6 m)	554	6.7×10^6
0	284 (7×7 m)	384	12×10^6

There is an alternative suggestion which seems attractive, that is, configuration D of Section III which consists of a shield for high-energy neutrinos and a second neutrino beam with a 100-GeV steel shield for low-energy neutrinos for the bubble chamber. The cost of the steel is 1.6×10^6 dollars (plus costs of a second target and associated beam-transport system), and the low-energy neutrino flux is probably equivalent to curve C of Fig. 1 or the composite neutrino shield discussed above. For comparison of event rates, there is also an improvement factor due to the increased accelerator pulse rate at 100 GeV as opposed to 400 GeV. Another suggestion with promise is the Maschke suggestion, configuration E of Section III, which provides both high- and low-energy neutrino beams from one beam line. A high-energy neutrino beam is obtained by using target 1 with the movable plug in. The low-energy neutrino beam is obtained by using target 2 and the moveable plug out (to provide a decay zone). This scheme has only promise since many technical questions need to be studied and answered before such a system could be employed.

V. PHYSICS CONSIDERATIONS

The choice of a neutrino shield configuration and targeting energy determines the neutrino flux. If an earth instead of a steel shield would be adopted, the low-energy neutrino flux ($E_\nu < 20$ GeV) would be reduced. The effect of such a reduction in flux on the proposed experiments is examined in a gross way in Table II. Those experiments which primarily use the high-energy portion of the neutrino spectrum or which involve a large number of events ($> 10^5$), are described as being approximately unchanged by a reduction in the low-energy flux. The remainder of the experiments have the majority of the events in the low-energy region. In these cases, the total number of proposed physics events (by the experimenter) is recalculated for the reduced low-energy neutrino flux, as a crude indication of the effect. Since only the total number of events is listed, this tends to conceal the situation for some of the individual physics topics which depend on particular channels or reactions.[6] Table IV examines this subject further. In particular, the physics topics emphasized in the proposals are considered individually and estimates are made, in a number of cases, of the number of events involved in the topic for the choice of a steel or an earth neutrino shield.[6]

REFERENCES

[1] D. Theriot, Muon dE/dx and Range Tables: Preliminary Results for Shielding Materials, National Accelerator Laboratory Internal Report TM-229, March 1970.

[2] D. Theriot (National Accelerator Laboratory), personal communication, 1970.

[3] Information concerning heavy concrete (iron ore + cement) can be obtained from M. Goral, DUSAF; the steel costs have been detailed by M. Awschalom, and iron-ore information has been obtained from the DND Corporation and Inland Steel.

[4] The cross-section estimates were made by D. Theriot (National Accelerator Laboratory) and may change with more refined calculations.

[5] Figures 1 and 2 were obtained from F. Nezrick (National Accelerator Laboratory). Note that Figs. 1 and 2 are identical if it is recalled that 10^5 incident protons = 3280 interacting protons.

[6] Further discussion and details concerning neutrino reactions can be obtained from the summer-study report by L. Clavelli and R. Engelman, SS-199. There are a number of other summer-study reports which contain useful information on associated topics (i.e., SS-174, SS-200).

Table III.[a] Neutrino-Physics Proposals--Sensitivity to Low-Energy ν Flux.

	Number	Target	E_ν(GeV)	E_p(GeV)	$N_p(10^{19})$	No. Pix	Physics Topics Emphasized in Proposals	Proposed Physics Events	
								Steel Shield D=600 S=300	Earth Shield D=1400 S=1400
BC	20 ν	D_2	0-75 0-120	200 500	0.75 0.25	0.25×10^6	A	~30,000	5,000
BC	31 $\bar{\nu}$	H_2	0-100	500	1	1×10^6	ABDEIJG	~15,000	~ 4,500
BC	45 ν	H_2	5-50	200	0.2	0.2×10^6	BCDFIJKMN	~50,000	~ 15,000
BC	42 ν	D_2(TST) + Ne	8	200	0.05	1×10^6	ABDEFGI	~25,000	~ 7,500
BC	44 ν	D_2(TST) + Ne	0-75 0-170	200 500	0.5	0.5×10^6	ABCDFGIKMN	~50,000	~ 15,000
BC	53 ν	D_2(TST) +Ne +Pb	0-75 0-170	200 500	2	1×10^6	ABDEFGHILM	~ Unchanged	
BC	28 ν	Ne	0-150	200	2	1×10^6	FGHJKLN	~ Unchanged	
Hy	9 $\nu, \bar{\nu}$	$H_2(D_2)$	15-75 15-120	200 500	2 (2) 2	1×10^6	AGIJL	~ Unchanged	
C	1 ν	H_2, Pb	10-150 10-300	200 500	4	———	IHLGN	~ Unchanged	
C	21 ν	Fe	300±18	400	0.2	———	GILN	~ Unchanged	
C	38 ν	H_2, Al Fe, U	20-150 20-300	200 500	0.2	———	IHLGN		

BC = Bubble Chamber, Hy = Hybrid, C = Counters and Spark Chambers

Physics Topics: A. ν elastic form factors, B. 1-pion production (Adler test), C. vector-meson production, D. hyperon production $\Delta S = 1$, $\Delta S = 0$ (associated production), E. polarization, F. $d^2\sigma/d\nu dq^2$ at small q^2 (Adler test), G. total cross sections, H. four-Fermion interactions, I. $W^\pm$ search, J. (ν-$\bar{\nu}$) comparison, K neutral-current interactions, L. deep-inelastic scattering, M. inverse muon decay, and N. miscellaneous--heavy-lepton search, monopole search, A dependence.

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[a] This table was adapted from a table prepared by D. Yount (SS-174).

Table IV. Neutrino Physics Topics-Event Rate Estimates.

Physics Topics	Number of Events Expected For 10^5 Pix Run[a]		Cross Section and Energy Dependence Assumed
	Steel Shield	Earth Shield	
A. ν, $\bar{\nu}$ elastic			
1. $\nu + n \rightarrow \mu^- + p$	~6-10,000	~1,000-1,600	$\sigma_\mu(\nu) \simeq 10^{-38}$
2. $\bar{\nu} + p \rightarrow \mu^+ + n$	~2,000	~330	$\sigma_{el}(\bar{\nu}) = \sigma_{el}(\nu)/3 \simeq \frac{1}{3} \cdot 10^{-38}$
$\mu^+ + n$ (with recoil)	~500	~80	
B. 1-pion production			
from ν	~1,800-3,000	~600-1000	$\sigma \sim E_\nu$
from $\bar{\nu}$	~600	~200	
C. Vector meson production			
D. Hyperon production			
1. $\Delta S = 0$ from ν	~1250-2500	~400-800	$\sigma = \frac{\sigma_{el}}{20}$
2. $\Delta S = 1$ from $\bar{\nu}$	~300 vis. $(\Lambda+\Sigma)$	~100	
E. Polarization studies	150 (vis. Λ)	~50	
F. $d^2\sigma/dq^2$ at low q^2			
G. Total cross sections for H_2	$\sim 2.5 \times 10^4$	$\sim 8 \times 10^3$	$\sigma_{inel} = 0.8 \times 10^{-38} E_\nu$
H. Four Fermion interaction	~50	(Proposal 45)	
I. $W^\pm$ search	~50	(Proposal 45)	
J. ν-$\bar{\nu}$ comparison			
K. Neutral current interactions			
L. Deep inelastic scattering	~15-20,000	~6-8,000	
M. Inverse muon decay			
N. Miscellaneous			

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[a] We use the experimenter's estimate, or estimates if numbers are in more than one proposal. However, estimates are not included for all topics.

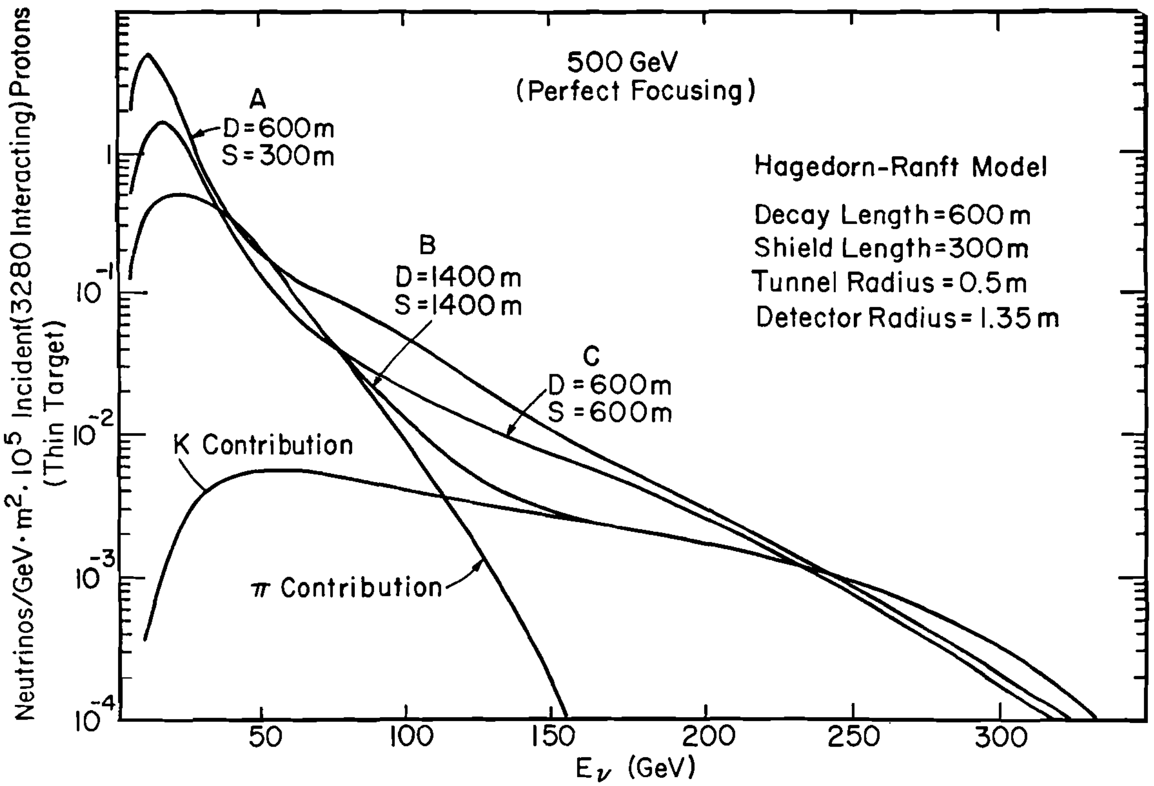

Fig. 1. The neutrino flux at 500 GeV for several different shield and decay lengths.

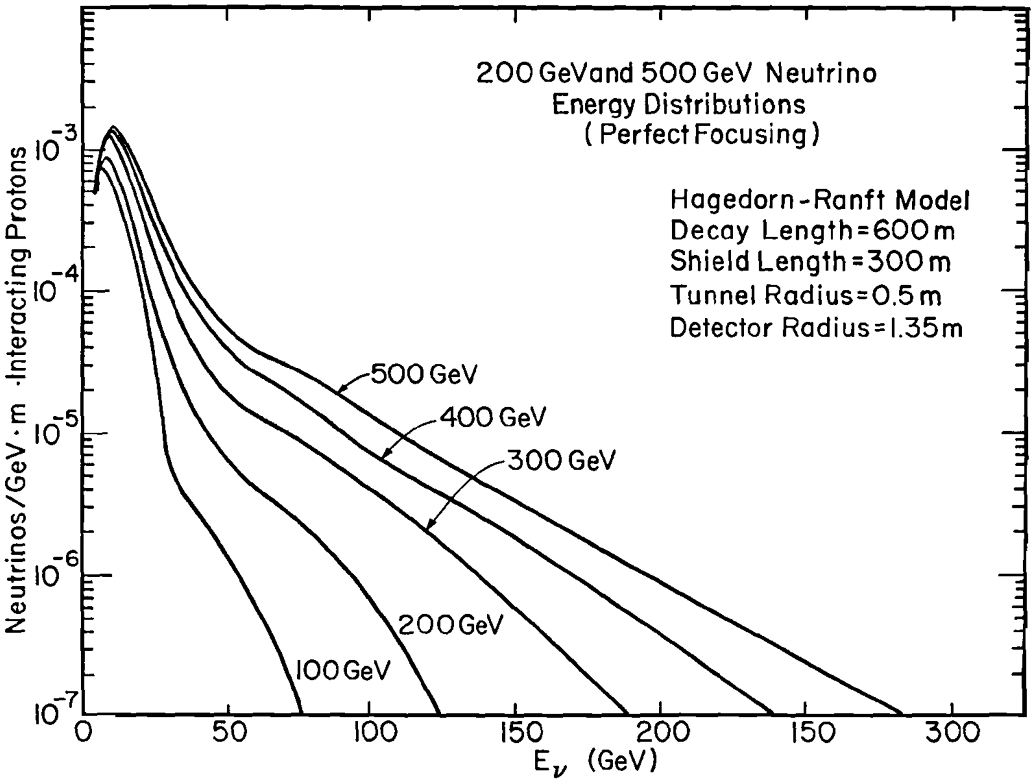

Fig. 2. The neutrino fluxes at 100, 200, 300, 400, and 500 GeV.