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Technical Memorandum 82027

Looking for Heavier Weak Bosons with DUMAND

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(NASA-TM-82027) LOOKING FOR HEAVIER WEAK
BOSONS WITH DUMAND (NASA) 10 p
HC A02/MF A01

N81-12828

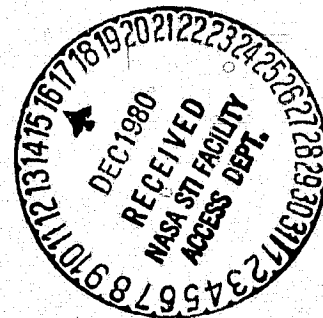
CSCL 20H

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63/72 39812

OCTOBER 1980

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771



Heavy Weak Bosons, Cosmic Antimatter and DUMAND:

I: Looking for Heavier Weak Bosons with DUMAND

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Abstract: We discuss a possibly unique opportunity afforded by a facility like that of DUMAND. A number of different theoretical developments indicate that one or more heavier weak bosons may coexist with the "standard" weak boson. If this is true, a broad program may be laid out for a search for the heavier W's via change in the total cross section for $\nu N \rightarrow \nu X$ due to the additional propagator, a concomitant search via the annihilation $\bar{\nu} e^-$, and a subsequent search (discussed in the following paper) for significant antimatter in the universe involving the same annihilation, but being independent of possible neutrino oscillations. The program is likely to require detectors sensitive to higher energies, such as acoustic detectors.

* Research supported in part by the National Science Foundation,
Grant No. PHY80-08548

I. INTRODUCTION

There are reasons to believe that a number of weak bosons exist:

- 1) We may very well have different generations gauge bosons just as exist for quarks and leptons. (1)
- 2) The increased interest and success in thinking about substructure "prequarks," "preons", or "rishons" may lead to heavier composite systems of all spins. (2)
- 3) Superunification investigations have recently led to a natural composite picture. (3)
- 4) Heavy "right-handed" W 's may arise if parity is spontaneously broken. (4)
- 5) Heavy "right-handed" W 's may arise in a gauge hierarchy of grand unified theories. (5)

These are not all of the contexts in which heavier W 's arise. There is the general question about which gauge group is involved in the weak interaction field theory.

It is quite likely that only higher energy facilities like DUMAND could be used in a search for these new particles, in contrast to the up-and-coming search for the "standard" W . For clarity in presenting our program, we will assume that two W 's exist, W_1 and W_2 , with masses

$$M_1 \approx M_W = \frac{37.4}{\sin\theta_W} \approx 80 \text{ GeV}/c^2, \quad (1)$$
$$M_2 \gtrsim 3M_W.$$

In section 2, we shall discuss how the presence of the second W changes the hallmark of the standard DUMAND W search, the propagator bendover in

$$\nu N \rightarrow \mu X. \quad (i)$$

The " W^- factory" idea for DUMAND, (6)

$$\bar{\nu}_e e^- \rightarrow W^-, \quad (ii)$$

can be extended to the heavier W_2 case. There are, in fact, some advantages in doing so, relative to the lighter W . We discuss this in section 3.

The final step in our program addresses the profound question of whether or not large regions of antimatter exist in the universe. Neutrino astronomy with heavier W 's playing a key role can answer this question and is discussed in section 4 and the companion paper II.

The new issue of neutrino oscillation and mass does not becloud our program. Rather, the possible existence of right-handed (left-handed) neutrinos (antineutrinos) adds to its attractiveness. We shall comment on the relevance of this issue in each section.

II. INELASTIC NEUTRINO SCATTERING

The propagator due to the W-boson should be clearly visible in deep inelastic y -distributions for reaction (1).⁽⁷⁾ For our present purposes, we have investigated how the total cross section changes due to two W's. The old, single bendover will be seen to have additional structure. The y -distribution discussion will be included in an amended edition of this paper.

We can draw upon recent work⁽⁸⁾ on doubling weak bosons, for a representative calculation. Our philosophy is quite different, however. Rather than concentrate on the lighter W_1 , and its phenomenology, the emphasis is on the heavier W_2 . In the event that $M_1 \approx M_W$, the search for more involved structure in weak interactions will require higher energies and a focus on W_2 .

Define
$$\kappa \equiv \left(\frac{M_2}{M_W}\right)^2, \quad \epsilon \equiv 1 - \left(\frac{M_1}{M_W}\right)^2. \quad (2)$$

Implementing (1),

$$\kappa \gg 1, \quad \epsilon \ll 1. \quad (3)$$

Then the leptonic decay widths ($W_1 \rightarrow \ell \nu$) are

$$\frac{\Gamma_1^\ell}{M_1} \approx \frac{\Gamma_W^\ell}{M_W} \approx 0.3\%,$$

$$\frac{\Gamma_2^\ell}{M_2} \approx \epsilon \kappa \frac{\Gamma_W^\ell}{M_W}. \quad (4)$$

We further stipulate

$$\kappa \epsilon \approx 1, \quad (5)$$

although larger values of $\kappa \epsilon$ will still leave us with sufficiently small total widths ($\Gamma = 12 \frac{\Gamma_W^\ell}{M_W}$ for the usual single-boson 3-generation model).

The standard propagator is now replaced:

$$\frac{1}{1+z} \rightarrow \frac{1}{1+z} \frac{2z+R}{z+R} \quad (6)$$

where

$$z \equiv Q^2/M_W^2, \quad Q^2 = - (4\text{-momentum-transfer})^2 .$$

With a numerical integration over the parton form of the deep inelastic differential cross section, the question of how much the total cross section is changed can be answered. Noting $\kappa = \infty$ corresponds to the old standard, we look at the deviation from the single-boson total cross section in Fig. 1 for the case $\kappa = 10$. The deviation scales in s/M_W^2 . For $M_W = 80$, the cosmic ray energy is

$$E = 3.4 \frac{s}{M_W^2} \text{ TeV}, \quad \text{TeV} = 10^{12} \text{ eV} . \quad (7)$$

The asymptotic value for Fig. 1 is .36 .

The conclusion is that a 20% increase shows up around the next scale

$$s/M_W^2 = \kappa . \quad (8)$$

(Remember that the first propagator effect takes place around $s/M_W^2 = 1$.)

We comment on this result by way of a list of points for future study:

- 1) As we increase κ without decreasing ϵ , the deviation can be larger.
- 2) It appears that acoustic detectors are not crucial for this stage of our program. For very large κ , the deviation is small, anyway.
- 3) The y -distributions should be examined in detail for bins in the TeV range, in the 10 TeV range, and so forth.
- 4) What if there are neutrino oscillations? Suppose that neutrinos oscillate into antineutrinos. In that case, their helicity is then wrong for the V-A charged currents. However, V+A currents and associated (heavy) weak bosons B then come into play. We would see a new incoherent contribution to deep inelastic events at the higher energies if B 's exist. If the neutrinos oscillate among the generations (e, μ , τ , ...), the final lepton signature is changed. But the τ and μ signatures are both viable. In any case, the total neutrino flux is not so small that oscillations are a problem.
- 5) It will be of interest to extend the calculations ⁽⁹⁾ for the reaction,



where the B_i are actually produced. For larger $\epsilon\kappa$, we could have significantly larger cross sections than in the standard model.

- 6) Sequential W 's should also be considered. ⁽¹⁰⁾
- 7) The ratio examined here is insensitive to many details such as scaling violations.
- 8) Finally, we emphasize again that it is possible that DUMAND could distinguish between various weak-EM gauge models.

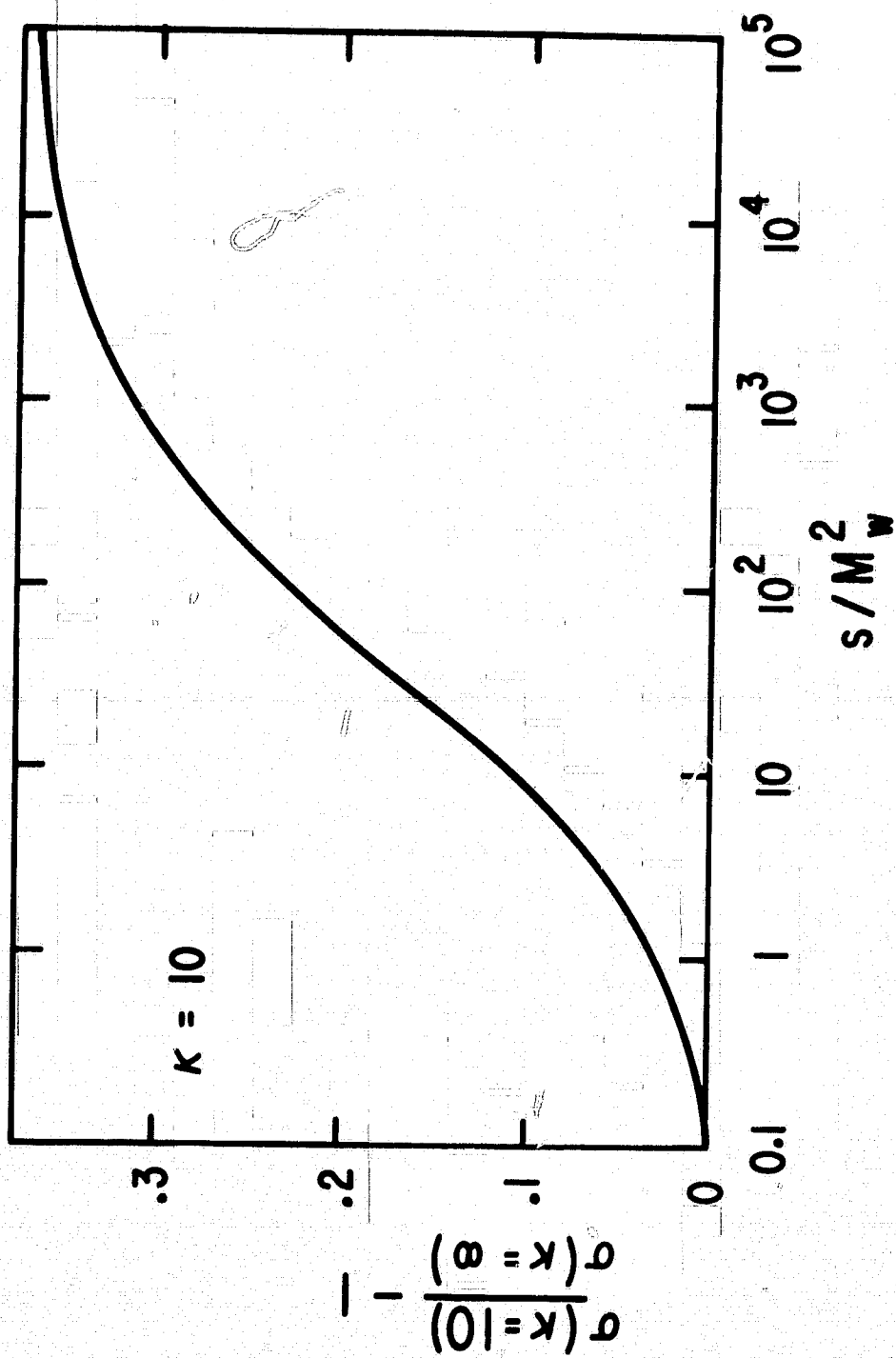


Fig. 1. Total νN inelastic cross section increase due to a second weak boson with $\kappa = 10$.

III. NEUTRINO-ELECTRON ANNIHILATION

The resonance reaction (ii) has been the subject of a proposal for a DUMAND cosmic ray experiment. (11) However, for a standard weak-boson mass, there may be severe background problems from the general reaction (i). We note that the cosmic neutrino must now have energy

$$E = 6.26 \frac{s}{M_W^2} \text{ PeV} ,$$

$$\text{PeV} = 1000 \text{ TAV} = 10^{15} \text{ eV} , \quad (9)$$

for $\bar{\nu}_e e^-$ c.m. energy \sqrt{s} .

If there is a heavier W, on the other hand, the background flux will have dropped off and we are back in business. The heavier of any forest of resonance spikes will stand out. It is here where acoustic detector developments are helpful. If we have a detection system which is (increasingly) sensitive to higher energies, then the new mass scales in weak interactions and lower backgrounds are at hand. (See paper II.)

If the flux and detector energy-dependence is negligible over the boson resonance width, the relevant quantity for the event rates is

$$\int \sigma_{\text{res}} dE = \frac{1}{2m_e} \int \sigma ds = \frac{1}{2m_e} 24\pi^2 \frac{\Gamma_i^\ell}{M_i} \quad (10)$$

for narrow total width Γ_i . We see that heavier bosons may very well have an increase in rates for a given flux and detection efficiency. The fact that acoustic detectors may be increasingly sensitive to higher energies and that the backbody process (see paper II) yields a shoulder in the flux of $\bar{\nu}_e$ makes an even stronger case here.

Even if there are only extragalactic neutrinos left above a certain energy, there are showers to be expected from deep inelastic scattering (by the same neutrinos). However, this background is small:

$$\frac{\int \sigma_{\text{back}} dE}{\int \sigma_{\text{res}} dE} \approx \frac{\langle \sigma_{\text{back}} \rangle \Delta S}{24\pi^2 \frac{\Gamma_i^\ell}{M_i}} \approx \frac{\langle \sigma_{\text{back}} \rangle \Gamma_i}{2\pi^2 / M_W^2 12\Gamma_i^\ell} \kappa_i ,$$

$$\kappa_i = \left(\frac{M_i}{M_W} \right)^2 \quad (11)$$

For

$$2\pi^2 / M_W^2 = 1.2 \times 10^{-30} \text{ cm}^2 , \quad \langle \sigma_{\text{back}} \rangle \approx 3 \times 10^{-34} \text{ cm}^2 ,$$

$$\Gamma_i = 12 \Gamma_i^\ell , \quad \kappa_i = 10 \quad (12)$$

the number is 2.7×10^{-3} .

If the $\bar{\nu}_e$ oscillate into other neutrino states, then we lose events. But an important point is that the counterpart left-handed $\bar{\nu}_e$ [arising, perhaps, from ν_{eL} transitions into $(\bar{\nu}_{eL})$] will then produce the "right-handed" W_R and we can rephrase everything in terms of W_R sequences.

IV. SEARCH FOR ANTIMATTER

The third leg of this program for DUMAND involves the symbiotic relation between the existence of a heavy W and the fact that high energy $\bar{\nu}_e$'s may come from large scale, distant antimatter sources. If the existence of heavier W 's can be established by the propagator effect, say, of section 2, then we can turn the resonance analysis discussed in section 3 around. The $\bar{\nu}_e$ flux can be determined—the expected number of events is a strong function of the acoustic detection characteristics—and the possibility of important extragalactic sources explored.

We leave the discussion of the third leg to the companion paper (II) where the event rates are discussed but we reiterate that any oscillation $\bar{\nu}_e \leftrightarrow \nu$ will not wash out this test for antimatter, since helicity is preserved. Thus sources of ν_{eL} will not contaminate the $(\bar{\nu}_e)$ flux. Even better, the existence of additional W_R 's will provide more signature for this important test of antimatter in the universe.

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BIBLIOGRAPHIC DATA SHEET

1. Report No. TM 82027	2. Government Accession No.	3. Recipient's Catalog No.			
4. Title and Subtitle Looking for Heavier Weak Bosons with DUMAND		5. Report Date October 1980	6. Performing Organization Code 660		
		8. Performing Organization Report No.			
7. Author(s) R. W. Brown and F. W. Stecker		10. Work Unit No.			
9. Performing Organization Name and Address Laboratory for High Energy Astrophysics				11. Contract or Grant No.	
				13. Type of Report and Period Covered TM	
12. Sponsoring Agency Name and Address		14. Sponsoring Agency Code			
		15. Supplementary Notes Proceedings 1980 DUMAND Summer Workshop			
16. Abstract <p>We discuss a possibly unique opportunity afforded by a facility like that of DUMAND. A number of different theoretical developments indicate that one or more heavier weak bosons may coexist with the "standard" weak boson. If this is true, a broad program may be laid out for a search for the heavier W's via change in the total cross section for $\nu N \rightarrow \nu X$ due to the additional propagator, a concomitant search via the annihilation $\bar{\nu} e e^-$, and a subsequent search (discussed in the following paper) for significant antimatter in the universe involving the same annihilation, but being independent of possible neutrino oscillations. The program is likely to require detectors sensitive to higher energies, such as acoustic detectors.</p>					
17. Key Words (Selected by Author(s)) Neutrinos, Weak Interactions, Vector Bosons, Unified Field Theory, Cosmology		18. Distribution Statement			
19. Security Classif. (of this report) UN	20. Security Classif. (of this page) UN	21. No. of Pages 10	22. Price*		