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POSSIBILITY OF DETECTING THE W BOSON BY MEANS OF THE POLARIZATION OF THE MUONS FROM THE $W \to \mu + \nu$ DECAY

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The most reliable information on the W boson is presently obtained from neutrino-beam experiments [1,2]. It follows from these experiments that if the W boson exists its mass is $m_W > 2$ GeV.

Besides experiments in a neutrino beam, experiments were made to observe the W boson in NN interactions [3, 4] (of the NN → NNW type), consisting of searches for high-energy muons emitted at large angles to the proton beam.

The search for the W boson in nucleon-nucleon interactions offer a number of advantages over experiments in a neutrino beam: larger value of the expected cross section [5], much higher intensity and energy of the proton beam compared with the neutrino beam. However, the very difficult background conditions, connected with the presence of muons from the $\pi \to \mu$ decay, make such experiments and their interpretation difficult. Therefore the upper limit obtained in [3] for the W production cross section, $\sigma_W < 2 \times 10^{-34}$ cm^2, is subject to an appreciable uncertainty connected with the estimates of the background due to the $\pi \to \mu$ decay.

In this paper we wish to call attention to an entirely different method of searching for W among the proton-nuclear reaction products.

The point is that the longitudinal polarization of the muons from the $W \to \mu\nu$ decay should have a sign opposite to that of the muons from the decays $\pi \to \mu + \nu$ and $K \to \mu + \nu$. The formula for the longitudinal polarization of $\mu^\pm$ in the $W^\pm$ system in the case of an arbitrary spin state of $W^\pm$ is

$$P(\mu^\pm) = \pm \frac{1 + (3/2)(\vec{\xi}\mathbf{n}) + (3/4)c_{nn} - (\mu^2/2m_W^2)(1 - (3/2)c_{nn})}{1 + (3/2)(\vec{\xi}\mathbf{n}) + (3/4)c_{nn} + (\mu^2/2m_W^2)(1 - (3/2)c_{nn})}, \qquad (1)$$

where $\vec{\xi}$ is the W polarization, $c_{nn} = c_{ab}n_a n_b$, c_{ab} is the W alignment tensor, $\vec{n}$ a unit vector in the momentum direction, μ the muon mass, and m_W the W-boson mass. The sign corresponds to the sign of the charge of $\mu^\pm$. It is seen from formula (1) that $P(\mu^\pm) = \pm 1$ practically always, with the exception of the exotic situation when the following conditions are satisfied: 1) $(\vec{\xi}\cdot\vec{n})$ is close to zero with accuracy $\sim\mu^2/m_W^2$, 2) $c_{nn} = -4/3$ with the same accuracy. The magnitude of c_{nn} for different W-production processes is given by the formula

$$c_{nn} = \frac{2}{3} - 2\frac{|\mathbf{Mn}|^2}{|\mathbf{M}|^2}, \qquad (2)$$

where $M = \vec{M}\vec{I}$ is the matrix element of the W-production process and $\vec{I}$ is the W polarization vector.

To have $c_{nn} = -4/3$, the μ emission direction in the W system should coincide rigorously with the direction of $M/|\vec{M}|$. This occurs only if all the particles involved in the process, including the muon, move in the same direction. In addition, the W iw produced in different reactions, and c_{nn} is defined as the average over all the reactions, and should therefore differ from $-4/3$. The foregoing arguments allow us to state that $P(\mu^\pm) \approx \pm 1$ accurate to μ^2/m_W^2. In the laboratory frame, the longitudinal muon polarization at $P(\mu^\pm) = \pm 1$ is given by the formula (v_μ N c):

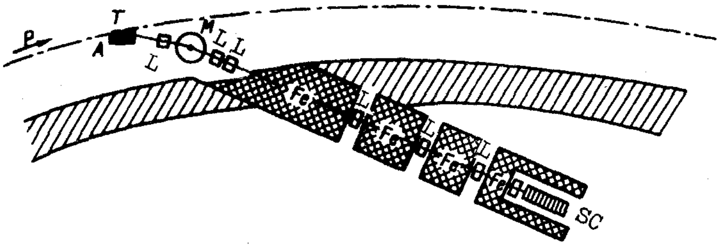
$$P_L(\mu_W^\pm) \approx \pm 1 - \frac{2\mu^2}{m_W^2}\,\frac{E_W}{E_\mu} \tag{3}$$

E_W and E_μ are the energies of the W boson and the muon in the lab. It is seen from (3) that there is practically no kinematic depolarization for the muons from W with energy $E_\mu \sim E_W$, i.e., $P_L(\mu_W^\pm) \approx \pm 1$.

On the other hand, the longitudinal polarization of the muons from the $\pi \to \mu$ decay depends on the slope of the spectrum of the parent pions. Calculations of the pion spectrum at a primary proton energy 70 GeV, based on various modesl of multiple production [6 - 10], show that the slope of the pion spectrum is such as to ensure $P_L(\mu_\pi^\pm) \approx \pm 1$.

Other muon generation mechanisms ($K \to \mu$, $\rho \to \mu^+\mu^-$, photoproduction, etc) make a much smaller contribution to the muon flux compared with $\pi \to \mu$ decay. Therefore the contribution of these mechnaisms practically plays no role in the feasibility of an experiment aimed at searching for the W boson is determined by the background due to the $\pi \to \mu$ decay.

Thus, compared with the earlier experiments [3, 4], the proposed method of searching for W in nucleon-nucleon interactions is much more specific, owing to the possibility of identifying the μ_W by the sign and magnitude of the longitudinal muon polarization. The setup for such an experiment is shown in the figure. At a proton-beam energy 70 GeV the optimal conditions (with respect to the $\pi \to \mu$ background) correspond to a muon emission angle $\sim 8°$ at $E_\mu \sim 30$ GeV. The muon polarization is determined from the asymmetry of the decay electrons following deceleration of the muons in the iron filter and their stopping in the spacrk-chamber plate. The total thickness of the spark-chamber plates corresponds to an energy interval



Experimental setup for the observation of the W boson in interactinos. p - internal proton beam of accelerator, T - Target, A - absorber of strongly interacting particles, L - lens, M - magnet, Fe - iron filter, SC - spark chamber

$\Delta E_\mu = 1$ GeV. The background from the $\pi \to \mu$ decay is suppressed by absorption of the pions produced in the target T in a layer of matter A (10 - 20 nuclear lengths) placed as close as possible to the target T. When the distance between the target and the layer A is increased, the setup registers the muons produced in the $\pi \to \mu$ decay, and this determines the μ_π polarization independently.

The proposed method makes it possible to identify reliably the production of a W boson in a nucleon-nucleon interaction in the accelerator of the High-energy Physics Institute (E_p = 70 GeV), if the production cross section is $\sigma_W \sim 10^{-36} - 10^{-35}$ cm^2/nucleon. The limiting value of the W-boson mass at E_p = 70 GeV is about 10 GeV.

In conclusion we note that the proposed methods of identifying the W by means of the sign of the longitudinal polarization of the μ_W meson may turn out to be very convenient in the search for W in νN and γN interactions.

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ERRATA

In the article by G. M. Drabkin et al., Vol. 8, No. 10, the two lower-right points of Fig. 1b (p. 335), at T = 349.25 and 346.65°C, should be dark (the pertain to curve 3).

In the article by V. D. Gorobchenko et al., Vol. 9, No. 4, the first literature reference [1] should read: "... ZhETF Pis. Red. 9, 155 (1969)[JETP Lett. 9, 91 (1969)]."

The title of the first article in Vol. 8, No. 10, by P. Varga et al., should read: "Generation of Infrared Radiation with the Aid of Polymethine Dye used in a Neodymium-glass Laser."

The authors of the article "Four Magnetic Iron Sublattices in Indium-gallium Iron Garnet," Vol. 8, No. 10, p. 346, are P. L. Gruzin, M. N. Uspenskii, I. S. Lyubutin, and L. A. Alekseev.