EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/83-61
3 May 1983

SEARCH FOR HIGH-MASS SEQUENTIAL LEPTONS
THROUGH THE CHANGE OF CHARGE ASYMMETRY IN
 $W^\pm \rightarrow \ell^\pm + (\text{NEUTRINOS})$ DECAY

D.B. Cline^{*)} and C. Rubbia
CERN, Geneva, Switzerland

ABSTRACT

We show that very massive charged heavy leptons can be detected as decay products in $W^\pm$ decays produced by proton-antiproton collisions. This technique is sensitive up to masses of $60 \text{ GeV}/c^2$ leptons if the associated neutrino is nearly massless. We show how this technique can be applied for W production at the CERN $p\bar{p}$ collider experiments and how it may be extended to the experiments at the 2 TeV $p\bar{p}$ collider at FNAL.

(Submitted to Physics Letters)

^{*)} Permanent address: Physics Department, University of Wisconsin, Madison, Wis., USA.

The production and decay of Intermediate Vector Bosons produced in proton-antiproton collisions is now accomplished at CERN and will be studied at FNAL [1]. The recent observation of events that are attributed to the Intermediate Vector Boson brings closer the possibility of using the $W^\pm$ particles to search for new leptons and heavy quarks [2,3]. Owing to the expected asymmetry of the masses of the different species of heavy-flavour quarks and leptons, the $W^\pm$ decays are sensitive to heavy-flavour particle masses near the actual mass of the $W^\pm$. For example, the decay modes

$$W^\pm \rightarrow t + \bar{b} \quad (\text{where } t \text{ is a } Q = +2/3 \text{ heavy quark} \\ \text{and } \bar{b} \text{ is the bottom quark})$$

and

$$W^\pm \rightarrow L + \nu_L \quad (\text{where } L \text{ is a new sequential lepton})$$

have an adequate phase-space factor for t -quark masses up to $\sim (50-60) \text{ GeV}/c^2$ and for L leptons to masses up to $\sim 60 \text{ GeV}/c^2$ if the associated neutrino (ν_L) is very low-mass [4].

In order to identify these new leptons we now consider the consequences of the maximal $W^\pm$ helicity in production, and the effects on the leptons in the decay. As is well known, this is expected to yield a charge asymmetry in the charged leptons at high transverse momentum [4,5]. The asymmetry is a strong function of the transverse momentum and laboratory angle of the lepton. The asymmetry has been studied in several theoretical works [5]. In this report we show that the introduction of heavy leptons in the $W^\pm$ decay final states modifies this asymmetry in a characteristic manner, and how the observation of the decay lepton p_T and angular distribution provides a technique for searching for the decay chain

$$W \rightarrow L + \nu_L (L \rightarrow \ell + \nu_\ell + \bar{\nu}_L)$$

up to L mass values of $\sim 60 \text{ GeV}/c^2$.

The present search for heavy sequential leptons has been carried out up to the mass value of $\sim 16 \text{ GeV}$ [6]. Thus we consider the mass range of $16-60 \text{ GeV}/c^2$ for this investigation. The properties of heavy leptons has been outlined in reference [7]. The expected decay angular distributions for polarized leptons follows from the classical (V-A) weak interaction theory [8].

We first consider the asymmetry of the charged leptons from the process

$$p\bar{p} \rightarrow W^\pm + X (W^\pm \rightarrow \ell^\pm + \nu_\ell) .$$

Several calculations of the resulting asymmetry of the charged lepton [5] have been made. In fig. 1a we show a scatter plot of the distribution for the angle between the charged lepton and the incident $\bar{p}$ at the CERN $p\bar{p}$ collider energy. Note the characteristic shape of the distribution which follows from the expected polarization of the $W^\pm$ particles.

It is straightforward to include the effects of the τ lepton using the classical decay characteristics [8]. Figure 1b shows the resulting scatter plot with the τ events included. Note that the low p_T lepton region is filled in, below $p_T \sim 20 \text{ GeV}/c$, and that there is a forward peaking of the distribution similar to that of $W \rightarrow \ell + \nu_L$ alone. It is this characteristic that makes it possible to search for $W \rightarrow L + \nu_L$.

The decay width of the W into the $L + \nu_L$ channel is given by

$$\Gamma(W \rightarrow L + \nu_L) = (GM_W^3/6\sqrt{2}\pi) [1 - (M_L^2/M_W^2)^2] [1 + 1/2(M_L^2/M_W^2)] .$$

This width is plotted in fig. 2. Note that L leptons of mass up to $60 \text{ GeV}/c^2$ give an appreciable partial decay width. (The decays of Z^0 are less useful, reaching L mass values of $\sim 25 \text{ GeV}/c^2$.)

We now turn to the properties of the decay leptons from the process

$$p\bar{p} \rightarrow W^\pm + X (W^\pm \rightarrow L^\pm + \nu_L) (L^\pm \rightarrow \ell^\pm + \nu_\ell + \bar{\nu}_L) .$$

For simplicity we consider leptons with a mass near $M_W/2$ in order to carry out simple analytic calculations ($M_L = 40 \text{ GeV}/c^2$). However, we expect that extension to masses of $\sim 20 \text{ GeV}/c^2$ and $60 \text{ GeV}/c^2$ will show the same characteristics. The $L^\pm$ produced in the decay of the $W^\pm$ are expected to be fully polarized, and thus we consider the decay of a polarized lepton,

$$L^+ \rightarrow \ell^+ + \nu_\ell + \bar{\nu}_L ,$$

via the standard (V-A) interaction. The angular distribution for the decay $\ell^\pm$ is given by

$$dW/d(\cos \theta)d\epsilon = G^2 M_L^5 / 192 \pi^3 [(1 - 3\epsilon) + \cos \theta(1 - 3\epsilon)]\epsilon^2 ,$$

where $\epsilon = p_\ell/(M_L/2)$ and θ is the angle between the L spin direction and $\ell^\pm$ momentum vector, and G is the Fermi constant. Integrating over ϵ , we find

$$dW/d(\cos \theta) = G^2 M_L^5 / 192 \pi^3 [1/2 - 1/6 \cos \theta] .$$

Integrating over θ we find the standard distribution for ϵ ; i.e.

$$dW = G^2 M_L^5 / 92 \pi^3 [3 - 2\epsilon] \epsilon^2 d\epsilon .$$

We take for the branching ratios of high-mass leptons the results of reference [7]. Note that the decay charged lepton from the L will be emitted in the backward direction compared to the L direction. This will modify the charge asymmetry of the charged leptons from $W^\pm$ decay (figs. 1a,b) and serve as a signature for the sequential lepton L. In fig. 3a we show the results of the simple analytic calculation for the $W \rightarrow L\nu_L$ decay compared with the $\mu\nu$ and $\tau\nu$ channels, assuming the L is at rest. In table 1 we show the increase in the population of the unfavoured angular distribution obtained from detailed calculations [9]. In fig. 3b we show the increase in the event distribution in the $p_{T,\ell}$ region of 6–30 GeV/c for the $L + \nu_L$ process as a function of the mass of L from these detailed calculations [9]. At large angles ($\cos \theta < -0.5$) there is a significant increase in the leptonic rate as expected from the decay of polarized L's. The ratio of event rates expected, with and without the L process, are also shown in fig. 3b; the ratio reaches ~ 2.0 and should be observable with an increase of (10–30) in the present statistics of $W^\pm$ events [2]. Note that if both the μ and e channels can be used, the statistics will double. Note also that this technique relies on the $W^\pm$ polarization expected for $p\bar{p}$ colliders and would not be useful for $W^\pm$ production in pp collisions.

There are several potential backgrounds for this observation. The main one comes from $W^\pm$ production with an unfavoured helicity due to sea ($q\bar{q}$) interactions. To illustrate this, we show as an example (fig. 3c) the expected $\ell^\pm$ angular distribution for the FNAL $p\bar{p}$ collider energy where the sea contribution is expected to be much larger [5,9]. Thus the sea-quark distribution can produce a backward peaking in the angle-asymmetry plot [9]. However, the shape and magnitude of this contribution will not generally fit the $L^\pm$ production and decay hypothesis. This illustrates the need to measure the charged lepton angular distribution at a variety of angles and different centre-of-mass energy, since the sea contribution is expected to depend on c.m. energy in a characteristic manner. We expect that at $p_T < 30$ GeV/c the L production and decay will change the asymmetry near $\cos \theta \sim -1$ for the FNAL $p\bar{p}$ collider energy as well.

It may be possible to search for the L lepton through hadronic decays of the lepton, i.e.

$$L \rightarrow \nu_L + (\text{hadronic jet}) .$$

In this case events with a single high- p_T jet and large missing energy would be observed. However, there are potential backgrounds from heavy-flavour production and calorimetry fluctuation that must be addressed. Of course, the observation of the correct number of “wrong asymmetry” leptons in the intermediate p_T , as well as the corresponding number of jets plus missing energy events, would provide additional evidence for the $L^\pm$ hypothesis.

We wish to thank G. Bauer, M. Mohammadi and J. Rhoades for help with calculations.

REFERENCES

- [1] C. Rubbia, P. McIntyre and D. Cline, Proc. Int. Neutrino Conference, Aachen, 1976 (Vieweg, Braunschweig, 1977), p. 683.
- [2] G. Arnison et al., Phys. Lett. 122B (1983) 103.
- [3] M. Banner et al., Phys. Lett. 122B (1983) 476.
- [4] See, for example, D. Cline, Proc. 1978 Neutrino Conference, Purdue, 1978.
- [5] F.E. Paige, Proc. Topical Conf. on the Production of New Particles at Super-High Energies, University of Wisconsin, 1979.
C. Quigg, Rev. Mod. Phys. 94 (1977) 297.
F. Paige, Proc. Conf. on Proton-Antiproton Collider Physics, Madison, 1981 (AIP Proceedings No. 85, 1982), p. 216.
- [6] C. Berger et al., Phys. Lett. 99B (1981) 489.
D.P. Barker et al., Phys. Lett. 45 (1980) 1904.
R. Brandelik et al., Phys. Lett. 99B (1981) 163.
- [7] Yung-Li Tsai, Phys. Rev. D4 (1971) 2821.
- [8] See, for example, L. Okun, Weak Interactions of Elementary Particles (Pergamon Press, Oxford, England, 1964).
- [9] For these calculations we have used the program ISAJET written by F. Paige and S. Protopopescu, BNL report 31987 (1981).

Table 1

Change of charge asymmetry due to new sequential leptons

M_L (mass) (GeV/c ²)	$\cos \theta$ range	$p_{T,\ell}$ range (GeV/c)	Fraction of events	
			Standard theory (e, μ , τ) (%)	Include L (e, μ , τ ,L) (%)
40	0-(-0.5)	6-30	2.7	4.8
40	(-0.5)-(-1)	6-30	2.7	5.3
40	0-(-1)	6-30	5.1	10.1

Figure captions

- Fig. 1a Scatter plot of the lepton p_T versus $\cos \theta$ from $W \rightarrow \ell + \nu_\ell$, where θ is the angle between the beam particle of charge Q and lepton of charge $(-Q)$.
- Fig. 1b Scatter plot of the leptons from $W \rightarrow \ell + \nu_\ell$ and the decay leptons from $W \rightarrow \tau + \nu_\tau (\tau \rightarrow \ell + \nu_\ell + \nu_\tau)$ with the same definitions as in fig. 1a.
- Fig. 2 Decay width for $W \rightarrow L + \nu_L$ and $Z^0 \rightarrow L + \bar{L}$ in arbitrary units as a function of L mass.
- Fig. 3a Results of a simple calculation of the $\cos \theta$ distribution of the ℓ leptons from $W \rightarrow L + \nu_L (L \rightarrow \ell + \bar{\nu}_\ell + \nu_L)$ compared with the distribution for the process $W \rightarrow \ell + \nu_\ell$ and $W \rightarrow \tau + \nu_\tau (\tau \rightarrow \ell + \nu_\ell + \nu_\tau)$ [9].
- Fig. 3b The ratio of rates of leptons produced from $W \rightarrow \ell + \nu_\ell$, $W \rightarrow \tau + \nu_\tau$, $W \rightarrow L + \nu_L$ compared to the rates for the same process without L final states as a function of the mass of the heavy lepton. The calculations come from Monte Carlo generated samples, each of 2000 events, using the ISAJET program [9].
- Fig. 3c Expected angular distribution of the ℓ leptons from $W \rightarrow \ell + \nu_\ell$ for $\sqrt{s} = 2000$ GeV $p\bar{p}$ collisions showing the backward peaking from the sea ($q\bar{q}$) production of $W^\pm$ events.

Fig. 1a

Fig. 1b

$$\Gamma(W \rightarrow L + \nu_L) = \frac{G m_W^3}{6\sqrt{2}\pi} \left(1 - \frac{m_L^2}{m_W^2}\right)^2 \left(1 + \frac{1}{2} \frac{m_L^2}{m_W^2}\right)$$

Fig. 2

Fig. 3