

## W's AT THE 200-GeV ACCELERATOR

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A search for the intermediate vector boson (W) has been made in neutrino-induced reactions at CERN and BNL and in p-p collisions at ANL and BNL. The first method is attractive in that actual events might be found which would reconstruct to a well defined mass. However, the sensitivity is limited by the total neutrino cross section ( $10^{-38} \text{ cm}^2$ ) and to masses near 1 BeV since the neutrino spectrum end point is  $\sim 2$  BeV at CERN and AGS. So we retreat from the better-defined situation in the bubble chamber to p-p collisions.

Many theorists have estimated the cross section for production of the W. The value depends of course on the mass of the W and on its branching ratio B for decay into  $\mu + \nu$ . All the methods that have presently been tried rely on the two-body decay as a signature for the existence of the W. They measure in fact  $\sigma \cdot B$ . A summary table for predictions of  $\sigma$  is shown below.

Reaction	$\sigma$	$M_W$	Reference
$\pi N, pN$	$10^{-32}$		Lee and Yang Phys. Rev. <u>119</u> 1410
$\pi+p \rightarrow W+p$	$10^{-32}$	1 BeV	Bernstein and Feinberg Phys. Rev. <u>125</u> 1741
$p+p \rightarrow W+D$	$10^{-34}$	1 BeV	Bernstein Phys. Rev. <u>129</u> 2323
$\bar{p}+p \rightarrow W+\pi$	$10^{-31}$	2 BeV	H. Mani Thesis Columbia
$p+p \rightarrow W+\alpha$	$5 \times 10^{-34}$	1 BeV	Nearing Phys. Rev. <u>132</u> 2323
$p+p \rightarrow W+p+p$	$10^{-31}$	3 BeV	Chilton et al.
$p+p \rightarrow W$ etc.	$\mu \times 10^{-35}$	3 BeV	Adair proposal to BNL and AGS

The two experiments that have been published use the high  $Q$  value of the decay  $W \rightarrow \mu + \nu$  signature. Since the transverse momentum characteristic of strong production of  $\pi$ ,  $K$  is  $\sim 200$  MeV/c, we might expect for a  $W$  of mass  $\sim 2$  BeV to see the muons from  $W$  dominate over the muons from  $\pi$ ,  $K$  decay at large angles to the incident proton beam.

The AGS experiment uses range to look for muons at high energy and large angle. The ANL experiment looks at large angle and then investigates the muon momentum spectrum after an absorber to verify that it is the residual spectrum from decay.

The residual background comes from muons produced at high momentum transfer either by multiple processes or from targets upstream of the main target which simulate high momentum transfer. These can be subtracted, in principle, because they are dependent upon the density of the target since the high-energy muons must come from pion decay before the pion is degraded by a further interaction. If we reduce the density this contamination will increase in a predictable way and allow an estimate of the contamination at high density.

The Adair experiment at BNL, which is in progress, relies on the fact that the longitudinal momentum of muons from  $W$ 's should also dominate over the muons from pions near the kinematical limit. With the model they use to calculate rates they expect to have 30% muons from the  $W$ 's compared to pions, kaons in the last 2 BeV of the muon spectrum.

This pionic contamination depends upon the density of the target so that subtraction is feasible by changing the density keeping the total amount of material fixed. Moreover Adair points out that since the spin of the  $W$  is unity, the muon is polarized opposite to the muons from pion or kaon decay. This experiment includes a polarization detector for the muons utilizing the decay asymmetry for the electrons from stopped  $\mu^+$ . We should expect this experiment to be more sensitive than the Lederman experiment although the mechanics of production are more involved in the understanding of the longitudinal momentum spectrum than the transverse.

At the 200-GeV accelerator the length of the muon absorber is  $\sim 200$  meters of iron to reach the end point of the spectrum, and the multiple scattering is  $\sim 8$  mrad in this amount of steel. The multiple scattering is comparable to the production angles involved and it is not clear that one can maintain the sensitivity of the low energy experiments at the high momentum. In any case an alternative approach occurred to us and we discuss it now.

First let us suppose that the  $W$  is produced in the c.m. system sharing the phase space with the two baryons. If the velocity of the c.m. is  $\gamma$  and the mass of the  $W$  is  $m_W$ , then at threshold of the muon decays at  $180^\circ$  in the lab, the momentum  $p_\mu \approx m_W^2/4\gamma$ . Remember  $\gamma \approx \sqrt{p/2}$ , where  $p$  is the momentum of the incident proton.

In Fig. 1 we show the  $\gamma$  of the c.m. system, in pp collisions, the threshold mass for the  $W$  and also  $p_\mu$  for the backward muon at threshold.

If the muon is produced this way, and if we have about a nucleon mass worth of energy available in the c.m. system over that needed to produce the W, then suppose that if the momentum of the W in the c.m. system is  $p_W$ ,

$$p_\mu \approx \frac{m_W^2}{\gamma(p_W + m_W)} .$$

If we are interested in high mass W's then the spread of momentum in  $p_\mu$  will be small and we will have a peak in the muon spectrum centered about  $m_W^2/4\gamma$ .

The alternative approach is to suppose, following Adair, that the W is produced with a small momentum transfer to one or the other of the two protons. It seems plausible to think that either one mechanism or the other will exist but probably not both. Anyway, if we say that the Wp system is created peripherally, then the backward muon from the forward-going state in the c.m. has a momentum  $p_\mu = m_W^2/4p$ , with p the incident proton momentum. This too will yield a peak since the momentum transfer is hypothesized to be small. The backward going Wp system will give a higher energy muon but it will be more spread in momentum also.

We suggest an experiment which is sketched in Fig. 2. We have a spectrometer which is sensitive in the muon momentum range 100 MeV/c - 500 MeV/c. Two feet of 10 kG field is more than enough. We

can also use the Adair polarization detector on the  $\mu^+$ . The experiment consists of measuring a two-dimensional plot of muon spectrum against incident momentum, varying the c.m. energy. Steps of about a nucleon mass seem sensible. The W will appear (if it exists) as an enhancement on this plot, and its position gives the mass.

It remains to estimate sensitivity. Crudely, assuming a c.m. solid angle of  $100 \mu\text{ster}$  and 10 g of target for 100 events/hour, then  $\sigma \approx 10^{-35} \text{ cm}^2$ .

If the reason that the W has not been observed so far is one of threshold then this sensitivity is more than adequate.

We have a simple experiment which uses the fact that a massive particle produced in the c.m. system gives a detectable signature from the kinematics of the backward direction. It looks amusing even though detailed calculation would be necessary to estimate pion contamination, etc.

### Background

One question that is not easy to answer is whether the possible muon signal is swamped by directly produced pions decaying to muons in the flight region from the target to detector. The kinematic limit comes at half the proton mass and the normal yield calculations are not applicable in this region so close to the limit. However, measurements at ANL and BNL in the backward region should settle this. As a reasonable guess we choose  $p + p \rightarrow D + \pi^+$ . This gives about 100 times the flux of

muons from the limit of cross section of the W search. This factor of rejection is fine at this momentum, and the decay length of the apparatus is of the order of 0.1 lifetimes of the pion. The background is clearly the serious problem in this experiment and without further measurements we cannot guarantee success, although the situation does not look hopeless.

## APPENDIX

Good things to know at high energies: with proton target, c. m. energy squared is

$$S = 2m_p p_{LAB} + m_\pi^2 + m_p^2$$

$$\approx 2m_p p_{LAB}.$$

The momentum in the c. m. system is

$$K^2 = \frac{\left[ s + (m_\pi - m_p)^2 \right] \left[ s - (m_\pi + m_p)^2 \right]}{4S}$$

$$\approx s/4 \text{ at H. E.}$$

Invariant 4-momentum transfer:

$$t \approx \frac{s}{2} (1 - \cos\theta) \qquad \frac{dt}{d\Omega} \approx \frac{s}{4m}.$$

Invariant crossed 4-momentum transfer:

$$\mu \approx \left( \frac{s}{2} - m_p^2 \right) (1 + \cos\theta) - \frac{m_p^4}{2s}$$

$$\gamma_{cm} \approx \frac{p_{LAB} + m_p}{\sqrt{2 m_p p_{LAB}}} = \sqrt{\frac{p_{LAB}}{2m_p}} + \sqrt{\frac{m_p}{2 p_{LAB}}}.$$

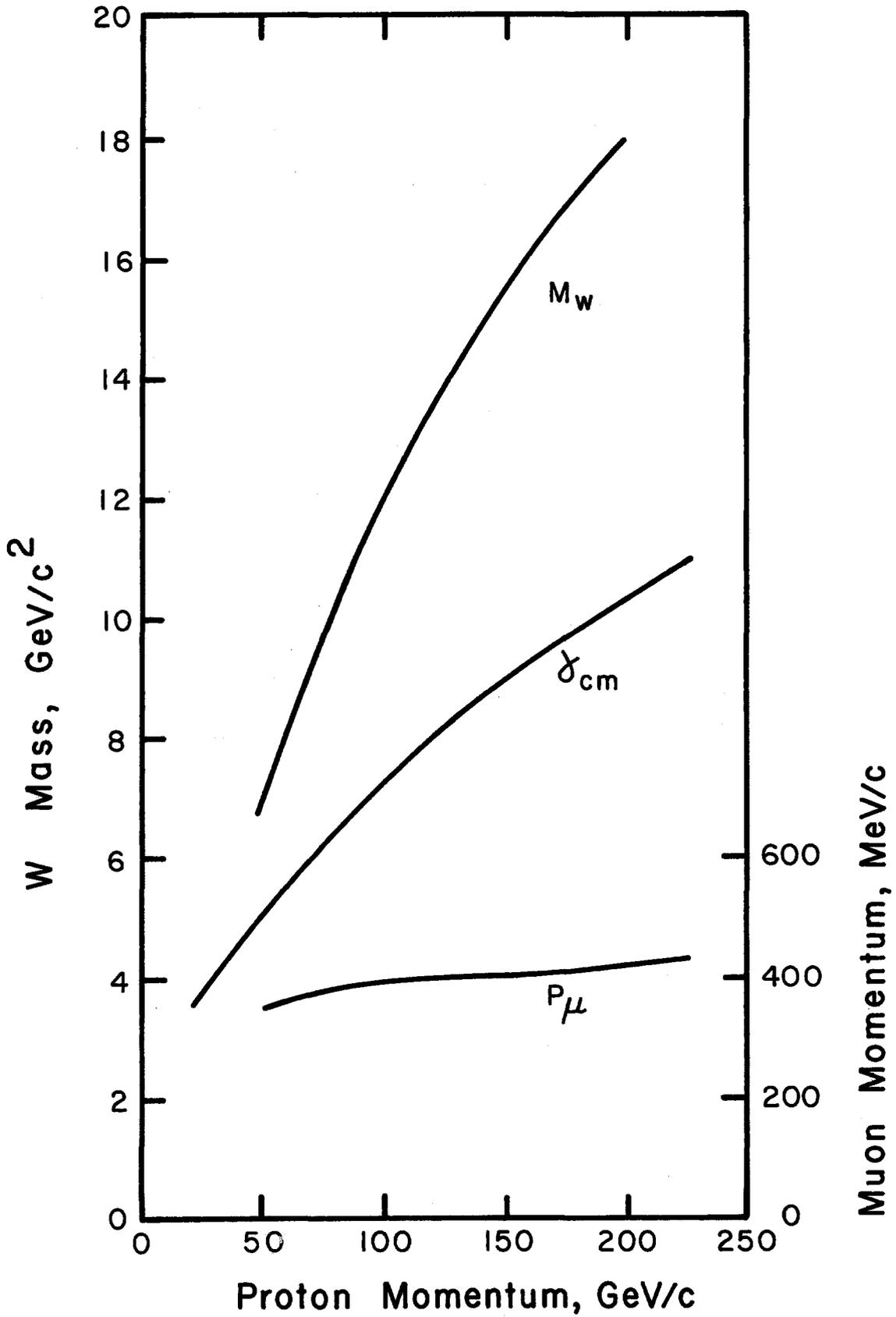


Fig. 1. For p-p collisions in the c.m. system,  $\gamma$  of the c.m., threshold mass of the W, and momentum of the backward muon at threshold.

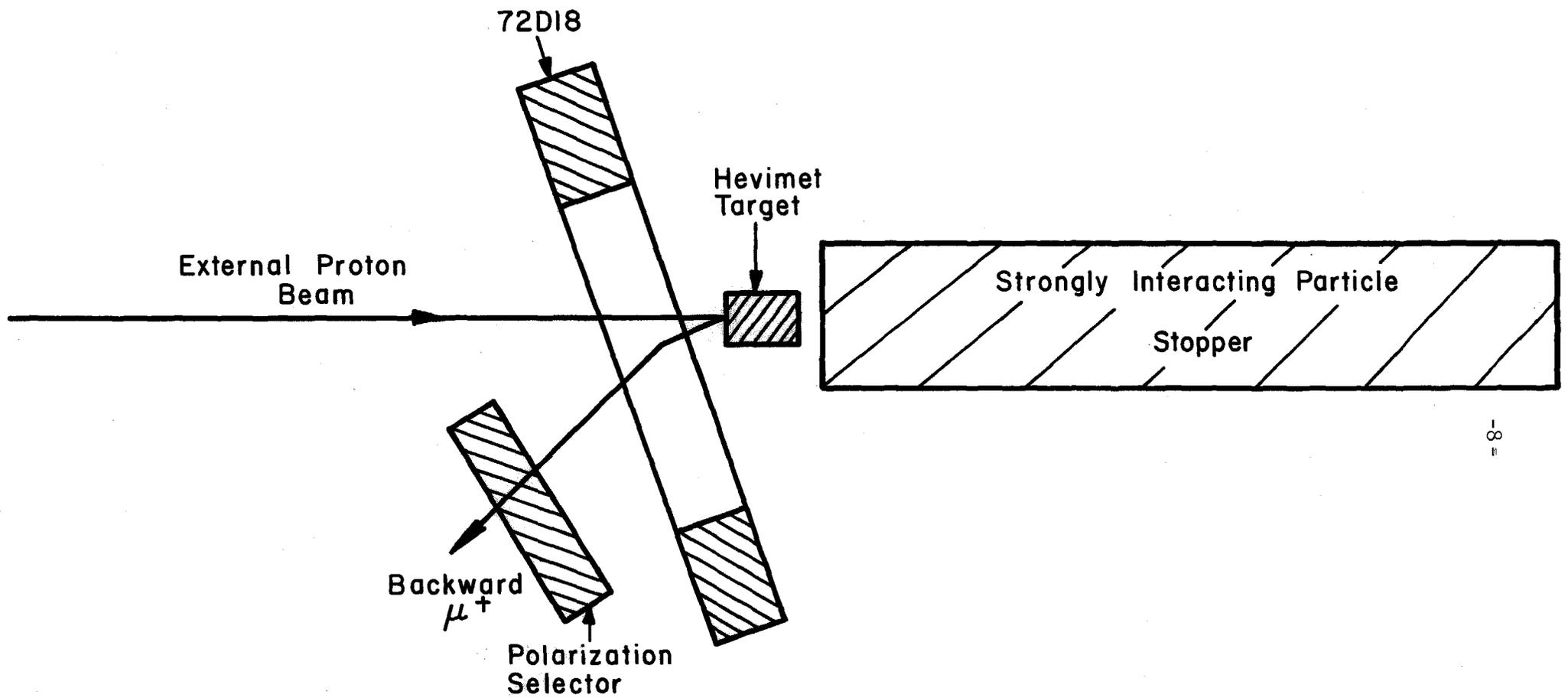


Fig. 2. Experimental arrangement.