SEARCH FOR INTERMEDIATE BOSONS USING MUONS

L. M. Lederman
Columbia University

August 8, 1968

Muon Beam

Yamanouchi[1] has designed a phase I (simple) muon beam using 6 quads and 2 dipoles. His beam is based upon:

(i) 5×10^{12} protons per pulse,

(ii) 30% interact,

(iii) 200-meter decay path,

(iv) 2.3×7.7 mrad acceptance into 8-in. aperture at 20 ft.

With this he reached 4×10^{7} muons at 100 BeV, $\Delta p/p \sim 5\%$. The area is of the order of 20 in.^{2} and can be shaped arbitrarily. If required, modest changes could easily raise this beam by a factor of 5-8 (10^{13} protons, 50% interact, 400-meter path, 4×7 mrad acceptance). Alternatively, these changes can be cashed in by raising the energy to $\gtrsim$ 150 BeV. At these energies, coherent production[2] of W's becomes feasible. Since detection of W production by neutrinos will be exceedingly difficult,* this is an essential component of the search for W's at NAL.

Rate

For 100-BeV muons on Fe, $\sigma_{coh}(Fe) = 2 \times 10^{-35}(k - 1)$ and

*The neutrino spectrum obtained with 200-BeV protons does not contain enough high-energy particles to produce W's coherently if $M_W > 2\,\text{BeV}/c^2$. This incoherent production for $M_W \sim 3\text{-}4$ BeV/c has serious background due to coherent 4-fermion interactions, e.g. $\nu + Z \rightarrow \mu + e + \nu + Z$ as discussed by Cline in NAL Summer Study Report B. 1-68-76.

$M_w = 5$ BeV/c^2, k = magnetic moment. Rate = $10^8 \times \left[(6 \times 10^{23})/60\right] E \times \sigma B X \times 2 \times 10^4$ events/day = 0.2 EXB,

where

E = efficiency

B = leptonic branching ratio

$\sigma \simeq 10^{-35}$

X = thickness of muon target (Fe).

Plausible guesses: E = 1/3, B = 1/4, so Rate = X/60 events/day. Then, X = 600 gm/cm^2 for 10 events/day. This implies 100 plates of Fe, each 6 grams thick. A 10-day run could be conclusive.

Signature

We observe:

$$\mu^+ + Z \rightarrow \nu \quad W^+ + Z$$
$$\hookrightarrow \mu^+ + \gamma \ .$$

The minimum momentum transfer is $\Delta = M_w^2/2E_\mu = 25/300$ BeV/c for $M_w = 5$. This is $\lesssim 100$ MeV/c and assures coherence with small form factor suppression. Thus, we look for a 100 - 150 BeV muon in and a $|\vec{P}_w|/2 \approx 50$ BeV/c muon out, at a maximum angle of $(M_w/2)/50 \sim 1/20$ radian. The claim here is that this is a unique and trouble-free signature. The apparent momentum transfer is ~ 3 BeV/c and $d\sigma/dq^2$ for elastic or inelastic muon collisions[3] at $q^2 = 10\,(\text{BeV/c})^2$ is $<< 10^{-34}$. Thus, a trigger which demands the incident muon be scattered through

> 1/30 and that no other particles be produced, should pick up nothing but W's! Pion contamination at 100 BeV/c should be $\lesssim 10^{-8}$ (30 mean free paths of filter) and the probability for even ten times this number of pions faking the signature and changing into a muon is completely negligible.

Arrangement

I see 100 iron plates 10 in. × 10 in. square, laced with scintillator of Charpak hodoscopes and preceded by a spectrometer to guarantee the incident muon momentum to ~ 5%. This could be a 6 in. × 4 in. aperture cryomagnet at 40 kG in 1 meter, using Charpak proportional wire chambers[4] with 20-cm lever arms.

The outgoing muon is momentum analyzed in a similar device and then passed through 10 nmfp of uranium to verify the mu-ness. The only technological burden is the operation of the wire chambers, pushed in the high speed mode. With a 6 in. horizontal distance, 100 wires implies a spacing of 1.5 mm (reasonable!) and requires that each wire be capable of taking a 1 mc rate. A scintillation hodoscope of 10 counters provides nanosecond timing for groups of 10 wires.

Conclusions

The experiment should be sensitive from $M_W \sim 2$ to 8 BeV/c^2 with decreasing coherence at high mass being compensated by larger transverse momentum. Given a signal, the mass can be measured by the maximum transverse momentum, and the magnetic moment by the unfolding of the angular distribution of leptons about the (forward) W direction:

$$(1 \pm \cos\theta)^2 \text{ for aligned W's, } g \neq 2,$$

$$\sin^2\theta \text{ for unpolarized W's, } g = 2.$$

Other leptonic weak interaction muon experiments can be very interesting if the cross section can be boosted by the coherence argument to $\gtrsim 10^{-36}$ cm^2, but all of these depend on working in a beam of 10^8 particles.

A final note: this kind of experiment would be ideally suited to the possibility of a "quick look" at 400-BeV physics at lower duty cycle, since the running time is very moderate. The mass search could then proceed to ~ 15 BeV/c^2 for M_W.