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ACCELERATOR DEPARTMENT

Informal Report

ELECTROMAGNETIC AND WEAK INTERACTIONS WITH $\bar{p}p$

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August 25, 1972

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INTERSECTING STORAGE ACCELERATOR NOTES

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The luminosities of $\bar{p}p$ interactions in the ISA are likely to be¹ at least 3×10^4 less than with pp interactions assuming no cooling, and at least 10^2 less even with cooling. Realistic² rates for electromagnetic and weak interactions with pp are only 500/day. It may, therefore, seem presumptuous to discuss the observation of such reactions with $\bar{p}p$. However, the cross sections for these reactions may be much larger with $\bar{p}p$ and the analysis of the results much easier. For these reasons I will proceed.

We will consider the following reactions:

$$pp \rightarrow \mu^+ + \mu^- + \text{anything} \quad (\text{em}) \quad (1a)$$

$$pp \rightarrow \mu^\pm + \nu + \text{anything} \quad (\text{weak}) \quad (1b)$$

$$\bar{p}p \rightarrow \mu^+ + \mu^- + \text{anything} \quad (\text{em}) \quad (1c)$$

$$\bar{p}p \rightarrow \mu^\pm + \nu + \text{anything} \quad (\text{weak}) \quad (1d)$$

A plausible model for these reactions, in which the lepton pair is massive, is³ that in which the nucleons are assumed to be made up of c partons and the above reactions are dominated by the point annihilation of a parton from one nucleon and an antiparton from the other (Fig. 1). The parton and antiparton will be of the same type for the electromagnetic interaction but different members of an isodoublet for the weak interaction (I will ignore λ quarks).

If for instance we assume the partons to be quarks (q_n, q_p, q_λ), then for the point electromagnetic interaction we have just

$$q_n + q_{\bar{n}} \rightarrow \mu^+ + \mu^- \quad (2a)$$

$$q_p + q_{\bar{p}} \rightarrow \mu^+ + \mu^- \quad (2b)$$

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and for the point weak interaction

$$q_p + q_{\bar{n}} \rightarrow \mu^+ + \nu \quad (3a)$$

$$q_n + q_{\bar{p}} \rightarrow \mu^- + \nu \quad (3b)$$

In all cases the lepton pair effective mass Q will depend only on the longitudinal momenta of the contributing partons $x_1 P$, $x_2 P$ where P is the momentum of the interacting nucleon beams. In fact

$$Q^2 = s x_1 x_2 \quad (4)$$

where s is the center of mass energy squared. If we assume the parton parton interaction to be truly "point-like" then the cross section for the production of a pair of mass Q is a function only of the probabilities g_1 and g_2 of finding the two partons with fractional momenta x_1 , x_2 times the appropriate coupling constants times the $(1/Q^4)$ squared photon propagator in the em case only. Explicitly, for any given pair of spin 1/2 partons whose identity we indicate by the subscripts i and j :

$$\frac{d\sigma_{ij}}{dQ^2} = \frac{4\pi\alpha^2}{3} \frac{e_i^2}{Q^4} F_{ij}(\tau) \quad \text{electromagnetic} \quad (5)$$

$$\frac{d\sigma_{ij}}{dQ^2} = \frac{g^2}{6\pi} F_{ij}(\tau) \quad \text{weak}$$

where $\tau = Q^2/s$, e_i is the partons charge/electron charge

$$F_{ij}(\tau) = \int_0^1 dx_1 \int_0^1 dx_2 \delta(x_1 x_2 - \tau) g_i(x_1) g_j(x_2)$$

i.e.

$$F_{ij}(\tau) = \int_0^1 \frac{dx_1}{x_1} g_i(x_1) g_j\left(\frac{\tau}{x_1}\right) \quad (6)$$

All these formulae have been given many times before,³ I give them only for completeness. They give "scaling" i.e. differential cross sections that depend only on Q^2/s and not on Q^2 or s separately (except for the propagator in em). They also relate the lepton pair production to the deeply inelastic structure function W_2 .

In this model W_2 is the sum of the contributions $(W_2)_i$ where i indicates each parton's identity and:

$$(W_2)_i = e_i^2 x g_i(x) \quad (7)$$

Now the g 's are the same in equations 6 and 7 but the sums to get the observed W_2 or $\frac{d\sigma}{dQ^2}$ are not. In the W_2 case the sum is over all partons and antipartons which for large x can probably be approximated by the contributions from just n and p type quarks:

$$W_2 \approx \sum_{q_p, q_{\bar{n}}} (W_2)_i = f_1(g_p, g_n)$$

In the $\frac{d\sigma}{dQ^2}$ case the sum will probably be dominated by the combinations of quarks indicated in equations 2 and 3. We will assume that the probability of finding an antiparton in a proton is small compared with that of finding a parton. The probability of finding an antiparton in an antiproton is, of course, the same as that for a parton in a proton. Then:

$$p + p \text{ (em)} \quad \frac{d\sigma}{dQ^2} \approx \sum_{\substack{i = q_n, q_p \\ j = q_{\bar{n}}, q_{\bar{p}}}} \left(\frac{d\sigma}{dQ^2} \right)_{ij} = f_2(g_p, g_n, g_{\bar{p}}, g_{\bar{n}})$$

$$p + p \text{ (weak)} \quad \frac{d\sigma}{dQ^2} \approx \sum_{\substack{i = q_p, q_n \\ j = q_{\bar{n}}, q_{\bar{p}}}} \left(\frac{d\sigma}{dQ^2} \right)_{ij} = f_3(g_p, g_n, g_{\bar{p}}, g_{\bar{n}})$$

$$p + \bar{p} \text{ (em)} \quad \frac{d\sigma}{dQ^2} \approx \sum_{\substack{i = q_n, q_p \\ j = q_{\bar{n}}, q_{\bar{p}}}} \left(\frac{d\sigma}{dQ^2} \right)_{ij} = f_4(g_p, g_n)$$

$$p + \bar{p} \text{ (weak)} \quad \frac{d\sigma}{dQ^2} \approx \sum_{\substack{i = q_p, q_n \\ j = q_{\bar{n}}, q_{\bar{p}}}} \left(\frac{d\sigma}{dQ^2} \right)_{ij} = f_5(g_p, g_n)$$

One can conclude

1. that the $\bar{p}p$ case is simpler to analyze since the cross section depends primarily on the distributions (g_p, g_n) of just the p and n type quarks, the dependence on the antiquarks $(g_{\bar{p}}, g_{\bar{n}})$ being small. In the electromagnetic $\bar{p}p$ the analysis is particularly simple since the two functions g_i and g_j in the integration (eq. 6) are always the same, this being so even if $g_{\bar{p}}$ and $g_{\bar{n}}$ are not small and cannot be ignored.

2. It is easier to relate the $\bar{p}p$ lepton pair production with $\sqrt{s}_2$ than the pp data. This is because they depend primarily on the same two functions g_p and g_n .

3. The combination of data from pp , pn and $\bar{p}p$ would be very powerful and probably sufficient to disentangle the contributions from individual quarks.

4. The cross section for lepton pair production from $\bar{p}p$ should be higher than those for pp , this becoming more pronounced as the Q is increased. This latter being because one expects it to be even less probable to find a very fast ($x \rightarrow 1$) antiparton in a proton than a slow one. The ratio is not of course known but on different assumption might lie somewhere between 10 and 100.

If we take the pair production rate in $\bar{p}p$ to be 30 times that in pp , then with a $\bar{p}p$ luminosity of $3 \cdot 10^{29}$ the rate of pair production would be 10^3 times less than with pp . Lederman² shows that with a fairly plausible piece of apparatus one might expect to see 500 em events plus 300 weak events per day with pp ($L = 10^{34}$). Thus with $\bar{p}p$ the same apparatus might be expected to yield

$$1/2 \text{ event/day (em)} + 1/3 \text{ event/day (weak)}.$$

This is really too low.

The situation could be improved either with the use of cooling to raise the $\bar{p}p$ luminosity or by increasing the collection efficiency of the apparatus. Cooling has been shown by Gluckstern⁴ to be ineffective for the improvement of pp luminosity but this reference in no way suggests that it would not work for $\bar{p}$'s. In fact it would suggest that a limit would only be reached when the $\bar{p}p$ luminosity approached the present pp luminosity. It is recognized, however, that the development of a cooling facility for $\bar{p}$'s is a very major undertaking and would not be considered unless there was an overwhelming need.

Increasing the collection efficiency of the apparatus seems far more reasonable. Lederman's device he estimates to have only 2% collection efficiency overall. The μ spectrometer is located only on one side of the intersection region and subtends only about 60° in the asymuthal plane. A fairly simple extension of Lederman's apparatus to asymuthally surround the intersection region would increase its efficiency by at least a factor 6 and an increase in its length would raise this factor

to 12 times. The resultant apparatus is shown in Fig. 2; it is no less than 11 meters diameter, 10 meters long and weighs 3200 tons. This may seem wild but as Lederman points out, it is simple. The weight is increased only 4x over Lederman's while the collection efficiency is increased 12x. With this apparatus and with an uncooled $\bar{p}p$ luminosity of $3 \cdot 10^{29}$ one would obtain

6 em events + 4 weak events/day.

The backgrounds would be negligible if we believe Lederman's estimates, since in $\bar{p}p$ the signal to background ratio will be 10 to 100 times better than in pp .

One concludes that while the rates are very low it would not be impossible to observe electromagnetic and weak lepton production using $\bar{p}p$ intersecting beams. It is further concluded that such observations could add a great deal to the understanding of such reactions. It is clear, however, that such an experiment is very expensive and near the limit of feasibility.

Fig 1

Fig 2

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3. For the original parton concept see R.P. Feinman, Phys. Rev. Letters 23, 1415 (1969); J.D. Bjorken and E. Paschos, Phys. Rev. 185, 1975 (1969). For more recent presentations see, for example, J. Kuti and V.E. Weisskopf, Phys. Rev. 4D 3418 (1971); S.M. Berman, CRISP report 72-32.
4. Gluckstern, CRISP report 71-24.