SLAC-PUB-1822
October 1976
(T/E)

SOME RESULTS IN $\mu p \to \mu h^{\pm} X$ PROCESS*

Minh Duong-van

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Presented at 18th International Conference on High Energy Physics
Tbilisi, USSR, 15-21 July 1976

*Work supported by the Energy Research and Development Administration.

I will report on two small aspects of deep inelastic particle production obtained by the following collaboration of SLAC and UC Santa Cruz. SLAC: K. Bunnel, M. Duong-van, R. Mozley, A. Odian, L. Schwarcz, F. Villa, L. Wang; UCSC: D. Cheng, D. Dorfan, S. Flatté, C. Heusch, G. Luxton, H. Meyer, W. Nilsson, A. Seiden, T. Schalk, A. Grillo, B. Liberman, L. Moss, C. del Papa. The data were obtained from a 14 GeV/c μ^+ beam on a hydrogen target in the region $Q^2 = .3 - 4$ GeV^2 and $\nu = 2$-12 GeV, using the SLAC 2m-streamer chamber.

We have learned from experiments on deep inelastic lepton-hadron scattering[1] that global aspects like the average charged multiplicity, the ratio of detected positive to negative hadrons, the inclusive structure function νW_2, etc., seem to vary with Q^2 up to $Q^2 \approx 1$ except in the regions of small $x = Q^2/2m\nu$ or $z = p^{had}_{lab}/\nu$.

In this talk, I will concentrate on the semi-inclusive structure function as a function of Q^2 and s.

A. STRUCTURE FUNCTION OF DETECTED HADRONS IN $\mu p \to \mu h^{\pm} + X$

The relevant variables used in this analysis are shown in Fig. 1 with Lorentz invariants:

$$Q^2 = -q^2$$

$$\nu = \frac{P \cdot q}{M}$$

$$\nu_h = \frac{h \cdot q}{m}$$

$$\kappa_h = \frac{h \cdot P}{M}$$

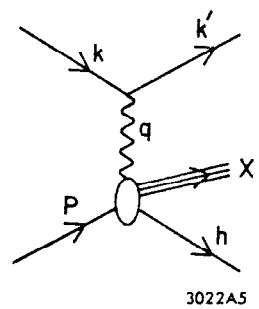

Fig. 1

Physically, ν_h is the energy loss of the lepton in the rest frame of the detected hadrons, analogous to ν, which is the energy loss of the lepton in the target proton rest frame. The observed hadron cross section, following Drell and Yan,[2] can be written as

$$\frac{d^4\sigma}{d\nu\, dQ^2\, d\nu_h\, d\kappa_h} = \frac{4\pi\alpha^2}{Q^4}\frac{E'}{E}\left[\mathcal{W}_2 \cos^2\frac{\theta}{2} + 2\mathcal{W}_1 \sin^2\frac{\theta}{2}\right]$$

From the quark-parton picture, for a given set of particles in the final states, we expect an actual scattering looks like Fig. 2. The two groups of particles (A and B) do not interact because of large $P_\perp$ separation of magnitude Q^2. Experimentally, we have noticed that the charge ratio $R = h^+/h^-$ in group B (forward in γp center-of-mass system) to be a factor of 2-3 larger than R in group A (not as

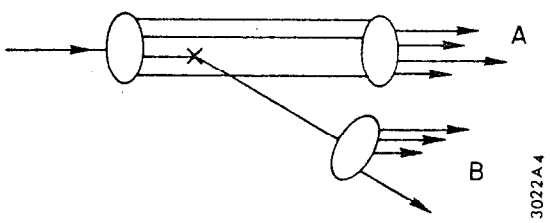

Fig. 2

forward). We define a variable z which, in leading order, is the fraction of the longitudinal momentum of the detected hadrons with respect to the scattered charged constituent:

$$z = \frac{\kappa_h}{\nu} \approx \frac{p_{lab}^{had}}{\nu} .$$

It can be shown that z is also the ratio of the momentum of the detected hadron to that of the struck quark-parton in the Breit frame. The structure function in a semi-inclusive process can be written as:

$$\lim_{Bj} M^2 \nu \mathscr{W}_1 = F_1(\omega, z, p_\perp^2)$$

$$\lim_{Bj} M \nu^2 \mathscr{W}_2 = F_2(\omega, z, p_\perp^2) .$$

Also, the scaling behavior of F's is equivalent to the scaling behavior of $\frac{1}{\sigma_T} \frac{Ed^3\sigma}{d^3p}$. We define here the structure function:

$$F_2(\omega, z, p_\perp^2) = \frac{z}{\sigma_T(\omega)} \frac{d\sigma}{dz}(\omega, z, p_\perp^2).$$

The scaling behavior at large z for two different values of s (Fig. 3) is expected from the quark-parton model.

The most interesting feature of this model was seen when we compared the structure function of $\mu p \to \mu h^\pm X$ with $e^+e^- \to h^\pm X$.

From Fig. 3, we obtain $\frac{1}{\sigma_T} \frac{d\sigma}{dx}$, which is simply the probability of finding the negative hadrons of fractional momentum z in the fragmentation of a quark whose type is determined by the value of x. At $x \approx 1$, the quark involved is mainly up-quark, etc. One can write down explicitly the contributions of each quark ($x = 2P/\sqrt{s}$):

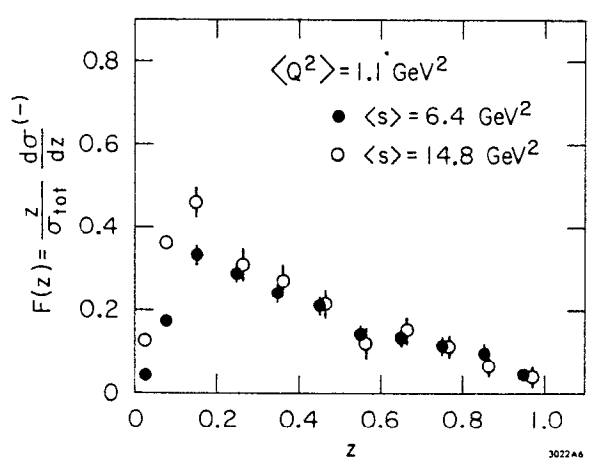

Fig. 3

$$\frac{1}{\sigma_T(\omega)}\frac{d\sigma^{h^\pm}}{dz} = \frac{\frac{4}{9}f_p^u(\omega)\left[D_u^{h^+}(z)+D_u^{h^-}(z)\right]+\frac{1}{9}f_p^d(\omega)\left[D_d^{h^+}(z)+D_d^{h^-}(z)\right]}{\frac{4}{9}f_p^u(\omega)+\frac{1}{9}f_p^d(\omega)} \tag{1}$$

where $f_p^u(D_u^h)$ is the probability of finding an up-quark (hadron) of fractional momentum $x(z)$ in a proton (up-quark). From symmetry, $D_u^{h^+} = D_d^{h^-}$ and $D_u^{h^-} = D_d^{h^+}$, Eq. (1) reduces to

$$\frac{1}{\sigma_T(\omega)}\frac{d\sigma^{h^\pm}}{dz} = D_u^{h^+}(z) + D_u^{h^-}(z) \tag{2}$$

In the case of colliding beams, one has (neglecting contributions from an s-quark)

$$\frac{1}{\sigma_T}\frac{d\sigma^{h^\pm}}{dx} = \frac{\frac{4}{9}\left[D_u^{h^+}+D_u^{h^-}+D_{\bar{u}}^{h^+}+D_{\bar{u}}^{h^-}\right]+\frac{1}{9}\left[D_d^{h^+}+D_d^{h^-}+D_{\bar{d}}^{h^+}+D_{\bar{d}}^{h^-}\right]}{\frac{4}{9}+\frac{1}{9}} \tag{3}$$

Noting $D_{\bar{u}}^{h^+} = D_u^{h^-}$, $D_{\bar{u}}^{h^-} = D_u^{h^+}$, etc., Eq. (3) reduces to:

$$\frac{1}{\sigma_T}\frac{d\sigma^{h^\pm}}{dx} = 2\left[D_u^{h^+}(x) + D_u^{h^-}(x)\right] \quad . \tag{4}$$

Since most colliding beam data are plotted as $s\,\frac{d\sigma^{h^\pm}}{dx}$, one can calculate this quantity from (4) by taking the value of $D_u^{h^+} + D_u^{h^-}$ measured from $\mu p \to \mu h^\pm X$ data, and multiplying by $2s\sigma_T$. Since Fig. 3 is for h^-, we multiply the calculated value by 2 to get $s\,\frac{d\sigma^{h^\pm}}{dx}$. Figure 4 shows the calculated value of $s\,\frac{d\sigma^{h^\pm}}{dx}$ and the experimental data from e^+e^- data at $s = 9.0$ GeV^2. Although the area under the curves is equal in normalization, the shape is different. Dr. Gail Hanson in the previous talk and Dr. R. Schwitters in in the rapporteur talk discussed the new variable $x_\parallel$ and plotted the quantity $s\,\frac{d\sigma}{dx_\parallel}$, where $x_\parallel$ is x projected in the direction of the jet axis. In the semi-inclusive scattering, there is no confusion between different axes since the direction

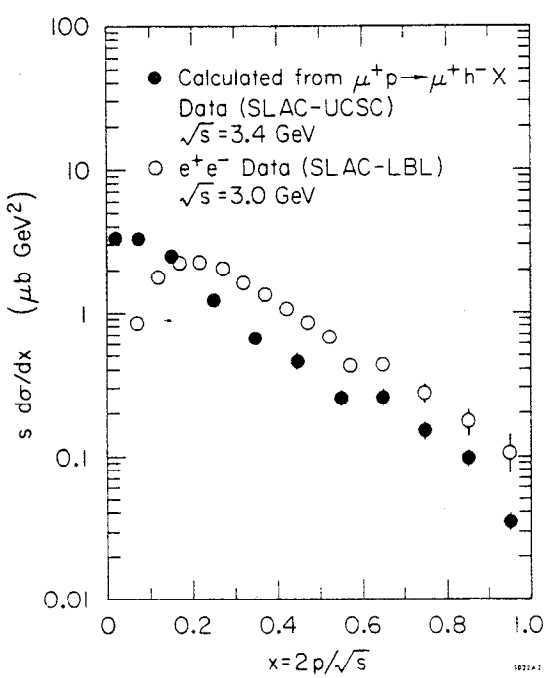

Fig. 4

of the virtual photon is the direction of the jet axis itself (in the low $Q^2 \approx P_\perp^2$ approximation). Figure 5 shows the predicted $s\,d\sigma/dx_\parallel$ and the e^+e^- data replotted along the jet axis. The agreement is impressive. One notices that in both curves a structure at $z = x_\parallel > .55$. The contribution due to ρ in this region at this energy is negligible in both e^+e^- data and our data (as pointed out by A. Seiden). If the structure is not a statistical fluctuation, the data may reveal the underlying production mechanism common to both processes.

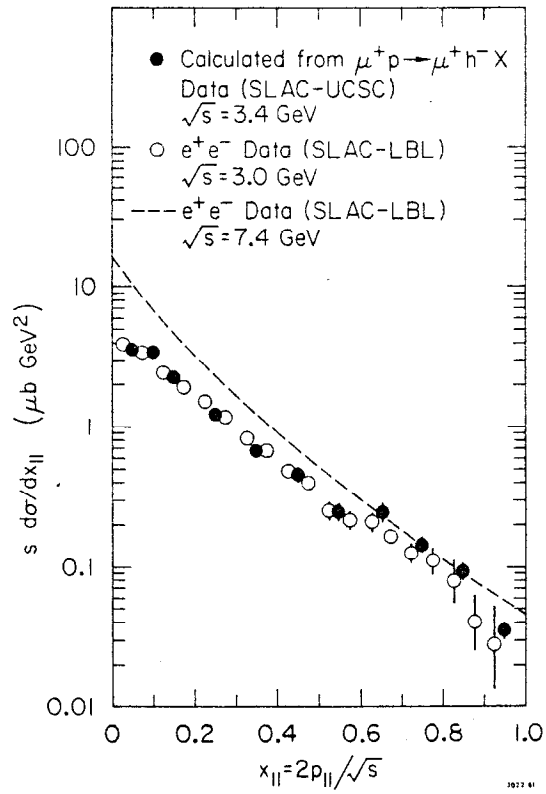

Fig. 5

I wish to interpret the data in the following way: our energies are far from being asymptotic. Most of the produced hadrons come from group A of Fig. 2, and the distribution would follow a hydrodynamic or thermodynamic characteristic, e^{-ax} (experimentally, $a = 5.8$). Only a small portion of the hadrons come from group B, which makes up the bump in the structure function. This is the reason why the charge ratio is roughly 2-3 instead of a very large value, an asymptotic value if all the hadrons come from the up-quarks. Comparisons between μp and e^+e^- structure functions at very high energies would be interesting. I would guess the bumps will be more prominent at these energies.

B. THE CHARGE RATIO $R = \frac{h^+}{h^-}$

As seen from the structure functions, the quark-parton description seems to be reasonable for both e^+e^- and μp processes, only in the high x, z regions. One consequence of this description is that the particle ratio should be predicted using the measured quark distribution functions. These distribution functions have been used to calculate the Drell-Yan[3] contribution to dileptons in hadronic processes, and the agreement with data is rather impressive.[4,5] Using the same distributions, one can calculate R for proton and neutron targets as follows. Call $u_p(x)$ the probability of finding an up-quark of fractional momentum x in a proton, and $u_{\pi^+}(z)$ the probability of fragmenting a π^+ of fractional momentum z from a

u-quark, etc., neglecting the contribution due to strange quarks, the ratio of $\frac{\pi^+}{\pi^-}$ in a proton target is:

$$R_p = \frac{\frac{4}{9}\left[u_p(\omega)u_{\pi^+}(z) + \bar{u}_p(\omega)\bar{u}_{\pi^+}(z)\right] + \frac{1}{9}\left[d_p(\omega)d_{\pi^+}(z) + \bar{d}_p(\omega)\bar{d}_{\pi^+}(z)\right]}{\frac{4}{9}[\pi^+ \to \pi^-] + \frac{1}{9}[\pi^+ \to \pi^-]} .$$

Using the functions derived by T. Goldman, u_p, $\bar{u}_p$, u_{π^+}, $\bar{u}_{\pi^+}$, u_{π^-}, $\bar{u}_{\pi^-}$, published in Ref. 4, we calculate the ratio R_p for an averaged value of $\langle z \rangle = .65$, an average between $z = .3$ and $z = 1.0$.

For the neutron target, $u_p(\omega)$ is replaced by $u_n(\omega)$, etc., and we calculate R_n. Figure 6 shows the predicted R_p and R_n and measured data for both proton and neutron target. Again, the quark-parton picture seems to be an adequate description of the observed physics in deep inelastic scattering in the large z region.

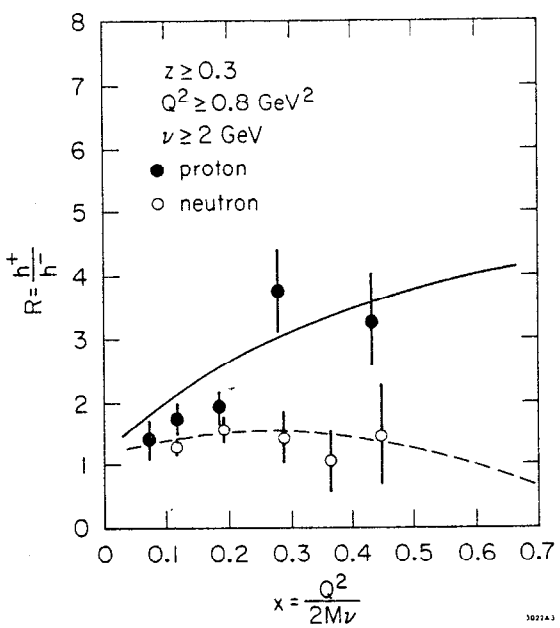

Fig. 6

It will be of interest to extract this charge ratio from e^+e^- data: If one would trigger on events with a π^- carrying a very large x in one jet, one would expect the charge ratio $R = \pi^+/\pi^-$ of the opposite jet should be roughly 2 to 3 in the large x region, similar to our data. Conversely, if the trigger is a π^+, then the charge ratio in the opposite jet is 1/2 to 1/3, as suggested by A. Seiden. If confirmed, this will be another confirmation of the fragmentation model.

I would like to thank Kirk Bunnel and Abe Seiden for helpful discussions.

REFERENCES

1. R. Mozley, Proc. Int. Symposium on Lepton and Photon Interactions at High Energies (Stanford University, California, 1975), ed. W. Kirk, p. 783.
2. S. Drell and T. M. Yan, Phys. Rev. Lett. 24, 855 (1970).
3. S. D. Drell and T. M. Yan, Phys. Rev. Lett. 25, 316 (1970).
4. M. Duong-van, Phys. Lett. 60B, 287 (1976); G. R. Farrar, Nucl. Phys. B 77, 429 (1974).
5. M. Duong-van, SLAC Report No. SLAC-PUB-1726 (1976).