A COMPARISON OF PROTON, ANTIPROTON AND MESON DISTRIBUTIONS
IN FINAL STATES OF DEEP INELASTIC MUON SCATTERING

The European Muon Collaboration

CERN¹-DESY(Hamburg)²-Freiburg³-Kiel⁴-Lancaster⁵-LAPP(Annecy)⁶-Liverpool⁷-
 Marseille⁸-Oxford⁹-Rutherford¹⁰-Sheffield¹¹-Turin¹² and Wuppertal¹³

J.J. Aubert⁸, G. Bassompierre⁶, K.H. Becks¹³, C. Benchouk⁸, C. Best^{10a},
 E. Böhm⁴, X. de Bouard⁶, F.W. Brasse², C. Broll⁶, S. Brown⁷, J. Carr^{10b},
 R.W. Clifft¹⁰, J.H. Cobb^{5c}, G. Coignet⁶, F. Combley¹¹, G.R. Court⁷,
 G. D'Agostini⁸, W.D. Dau⁴, J.K. Davies^{9d}, Y. Déclais^{6e}, U. Dosselli^{1f},
 J. Drees¹³, A. Edwards¹³, M. Edwards¹⁰, J. Favier⁶, M.I. Ferrero^{12g},
 W. Flauger², H. Forsbach¹³, E. Gabathuler¹, R. Gamet⁷, J. Gayler²,
 V. Gerhardt^{2h}, C. Gössling², J. Haas³, K. Hamacher¹³, P. Hayman⁷,
 M. Henckes¹³ⁱ, V. Korbel², U. Landgraf³, M. Leenen^{1j}, M. Maire⁶,
 H. Minssieux⁶, W. Mohr³, H.E. Montgomery¹, K. Moser³, R.P. Mount^{9k}, E.
 Nagy^{6l}, J. Nassalski², P.R. Norton¹⁰, J. McNicholas^{9m}, A.M. Osborne¹,
 P. Payre⁸, C. Peroni¹², H. Pessard⁶, U. Pietrzyk¹³, K. Rith³, M. Schneegans⁶,
 T. Sloan⁵, H.E. Stier³, W. Stockhausen¹³, J.M. Thénard⁶, J.C. Thompson¹⁰,
 L. Urban^{6l}, M. Villers⁹, H. Wahlen¹³, M. Whalley¹¹ⁿ, D. Williams^{7o},
 W.S.C. Williams⁹, J. Williamson^{11p}, S.J. Wimpenny⁷.

Abstract

New results on the forward produced protons and antiprotons in high energy muon-nucleon scattering are presented. Their W^2 , z and p_T^2 dependences are compared with those of the other charged hadrons. Significant differences are observed which can be related to the flavour content of the target and to a difference between the baryon content of quark and gluon jets.

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-
- (a) Now at JET, Joint Undertaking, Abingdon, England.
 - (b) Now at Lawrence Berkeley Laboratory, Berkeley, California, USA.
 - (c) Now at University of Oxford, England.
 - (d) Now at Plessey Defence System, Fareham, England.
 - (e) Now at Université d'Aix-Marseille II, Luminy, France
 - (f) Now at INFN, Sez. Padova, Italy.
 - (g) Now also at Istituto di Fisica, Università di Lecce, Lecce, Italy.
 - (h) Now at Beiersdorf AG, Hamburg, Germany.
 - (i) Now at IBAT, Essen, Germany.
 - (j) Now at Physikalisches Institut der Universität Bonn, Bonn, Germany.
 - (k) Now at California Institute of Technology, Pasadena, California, U.S.A.
 - (l) Now at Central Research Institute for Physics of the Hungarian Academy of Science, Budapest, Hungary.
 - (m) Now at British TELECOM, Coventry, England.
 - (n) Now at Durham University, Durham, England.
 - (o) Now at U.K.A.E., Windfrith, Dorchester, U.K.
 - (p) Now at RAL, Chilton, Didcot, Oxon, England.

In a previous publication [1] we reported on the production of forward protons and antiprotons in deep inelastic muon scattering. We pointed out that our results differed from those of earlier low energy e-p experiments [2], indicating that other mechanisms than target fragmentation were contributing to baryon production.

To further investigate these mechanisms, we have performed an analysis of our data, using larger statistics. The data were taken with the CERN SPS muon beam at energies of 120, 200, 240 and 280 GeV, scattering in a 6 m long hydrogen (deuterium) target. The charged hadron tracks were analysed in the EMC forward spectrometer [3,4].

In what follows standard kinematic variables are used [1,4]. Q^2 is the negative four momentum squared of the virtual photon, x_{Bj} the Bjorken variable, W the mass of the hadronic system and z the fraction of the virtual photon energy carried by the hadron. The transverse momentum p_T is measured with respect to the virtual photon direction. Table 1 summarises the characteristics of the data samples used, both for the muon kinematics and for the forward proton and antiproton yields. A total of 2043 protons and 1027 antiprotons were observed in the overall sample of $6.9 \cdot 10^5$ events.

The proton identification was performed by a large multicell Cerenkov counter filled with 1 atmosphere nitrogen or neon [3,5]. The Cerenkov counter has a length of 4 metres which, in the case of nitrogen filling, allows the pions and the kaons to produce mean values of 14.9 and 5.1 photoelectrons respectively at 25 GeV, thus ensuring a high efficiency for proton identification. In the case of neon filling, the proton sample is contaminated by misidentified pions and kaons. The level of contamination was estimated from the data as follows. Using nitrogen data, we measured pion and proton fractions in the appropriate ranges and assumed that these fractions were constant with momentum to derive the kaon fraction. Pion and kaon inefficiencies were derived from measurements with muon tracks and their contribution to the observed number of protons was then calculated using the previously determined fractions. We found that, in the case of neon filling, 18% of observed protons were misidentified pions and kaons. No correlation was found between the spatial distributions of the hadron tracks and the quantity of light they produced in the Cerenkov counter, thus ensuring a uniform distribution of the inefficient pions and kaons in terms of physical

variables. A constant 18% correction was then applied to the proton yield obtained when the Cerenkov counter was operated with neon.

The results below are discussed in terms of ratios p/h^+ and $\bar{p}/h^-$, where h^+ and h^- are the numbers of all positive and negative hadrons respectively within the momentum range of proton identification. Since the acceptance losses are similar for hadrons of the same charge and within the same momentum range, no corrections were needed for these ratios. The data on hydrogen and deuterium targets were not significantly different and were combined in this analysis.

To ensure an accurate determination of the hadronic variables, the analysis was restricted to those tracks fitting exactly the vertex reconstructed from the incoming and outgoing muon tracks. The effect on the ratio p/h^+ and $\bar{p}/h^-$ of the losses induced by reinteractions within the target was studied. A small variation of these ratios with the vertex position along the target was found, consistent with the theoretical expectation, while the hadronic variables did not show dependence on the vertex position. The ratios were corrected by extrapolating the observed values to the downstream end of the target [6].

It should be noticed that, due to the limited range of proton identification, a correlation exists between hadron and muon variables. In our overall sample of hadrons we get $\langle W^2 \rangle = 270 \text{ GeV}^2$, $\langle x_{Bj} \rangle = 0.06$ for $z < 0.3$ and $\langle W^2 \rangle = 110 \text{ GeV}^2$, $\langle x_{Bj} \rangle = 0.11$ for $z > 0.6$.

Fig. 1 shows the W^2 dependence of the ratios p/h^+ and $\bar{p}/h^-$ integrated over the whole x_{Bj} and z ranges. A relative excess of protons, with respect to antiprotons, is observed, which decreases as W^2 increases. As mentioned above, forward protons were already observed in low energy e-p experiments ($W^2 = 4$ to 9 GeV^2) [2]. Those were considered as target fragments which could not, at such energies, be clearly separated from current fragments. Such a source of extra protons can account for the pattern of the ratios p/h^+ and $\bar{p}/h^-$ observed in fig. 1, at small values of W .

The z dependence of the ratios p/h^+ and $\bar{p}/h^-$ is shown in Fig. 2 for different values of W^2 and x_{Bj} . Also shown are the results obtained by using the Lund Monte Carlo which incorporates fast baryon production via diquark

pair creation at a rate of 0.065 compared to quark-antiquark creation and slow baryon production from the target fragmentation [7]. For $W^2 < 100 \text{ GeV}^2$ (fig. 2a) we observe that p/h^+ is much larger than $\bar{p}/h^-$ at small z . Such behaviour is expected if target fragments significantly contribute to the proton sample. The effect is not reproduced quantitatively by the Lund model.

Fig. 2b shows the z dependence of the ratios p/h^+ and $\bar{p}/h^-$ integrated over the whole W^2 and x_{Bj} values. We observe a relative enhancement of the proton yield at intermediate z values and a general suppression of baryon production at large z . This suppression as well as the overall baryon yield are qualitatively reproduced by the model. For $x_{Bj} < 0.05$ (fig. 2c) the discrepancy between the ratios p/h^+ and $\bar{p}/h^-$ at intermediate z disappears, while for $x_{Bj} > 0.2$ (fig. 2d) this discrepancy is shifted towards the highest values of z .

In muoproduction, the value of x_{Bj} can serve as an indicator for the nature of the struck quark. For $x_{Bj} > 0.2$, around 90% (80%) of the struck quarks are u quarks in the case of a hydrogen (deuterium) target, while for $x_{Bj} < 0.05$, u and $\bar{u}$ quarks have equal probabilities to interact with the virtual photon. In our data, $\langle x_{Bj} \rangle = 0.09$. Within the conventional pictures of quark fragmentation, the proton spectrum is then expected to be harder than the antiproton spectrum, in the same way as positive mesons dominate negative mesons [8]. The reason for this is that positive hadrons are more likely to contain the leading struck quark which is most probably a u quark in muoproduction. The discrepancies between the ratios p/h^+ and $\bar{p}/h^-$ observed on figs. 2b and 2d indicate that the difference between the z spectra of protons and antiprotons is greater than the difference between the spectra of positive and negative mesons.

In previous publications [4,9] we showed, through the study of the transverse momentum properties of the final state charged hadrons and the observation of a double jet structure in the forward hemisphere, that high p_T events can be related to gluon emission. The p_T^2 dependence of the ratios p/h^+ and $\bar{p}/h^-$ is shown in fig. 4. For $W^2 > 200 \text{ GeV}^2$ an increase with p_T is observed for both p/h^+ and $\bar{p}/h^-$. Within the interpretation that large transverse momenta are reflecting the occurrence, more manifest at large W^2 , of gluon emission, such an increase would indicate that a more copious yield of baryons is associated with gluon fragmentation.

The rise of $\langle p_T^2 \rangle$ with W^2 has been proposed as a test of QCD predictions [10] and indeed such a rise was observed in our data [4]. We have compared the evolution with W^2 of $\langle p_T^2 \rangle$ of protons and antiprotons with that of the other charged hadrons. Fig. 4a shows that the rise of $\langle p_T^2 \rangle$ is faster for the protons and antiprotons than for all hadrons. For very low W^2 , the ratio $\langle p_T^2 \rangle_p / \langle p_T^2 \rangle_{h^+}$, is less than one, which may be a result of a significant target fragment contribution to the proton sample, as mentioned earlier.

As a further step in investigating the relation between the transverse momentum properties of an event and its baryon content, we have compared the p_T^2 distributions of the associated charged hadrons from two classes of events defined as follows:

Class A consists of events which contain an identified proton or antiproton.

Class B consists of events which have either a pion or a kaon within the proton identification range.

The identified particle was removed from each event and the p_T^2 distributions of the remaining hadrons in the two classes were then compared by plotting their ratio.

Fig. 4d shows that not only do the proton and antiproton yields increase at large p_T but also the remaining hadrons in events containing a proton or an antiproton have larger p_T in comparison with the hadrons of the other events. This might reflect a simple p_T compensation. On the other hand, the fact that a proton (antiproton) is accompanied by high p_T hadrons is also the behaviour expected if the protons and antiprotons were components of high p_T multi-particle jets, such as when a gluon is radiated by the struck quark.

In conclusion, the distributions of protons and antiprotons, as observed in our data, differ in many respects from those of the other charged hadrons. In order to describe qualitatively the relative behaviour it is necessary to invoke a dependence on the nature of the target, either directly in terms of target fragments at low W^2 or indirectly through a dependence on the flavour of the interacting quark. An enhancement of baryon yield is observed at large p_T which could be connected with gluon fragmentation.

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Table 1 - Muon kinematics and observed numbers of protons and antiprotons in each data set.

Target Beam energy	Kinematic cuts	Number of events after cuts (10^3)	$\langle Q^2 \rangle$ (GeV^2)	$\langle x_{Bj} \rangle$	$\langle W^2 \rangle$ (GeV^2)	Momentum range for proton identification (GeV)	Observed number of protons	Observed number of antiprotons
H_2 120 GeV	$Q^2 > 2 \text{ GeV}^2$ $20 < \nu < 100 \text{ GeV}$	146	8	0.095	92	25-38	279	111
H_2 200 GeV	$Q^2 > 2 \text{ GeV}^2$ $20 < \nu < 180 \text{ GeV}$	230	12	0.092	172	25-38	890	412
H_2 240 GeV	$Q^2 > 2 \text{ GeV}^2$ $40 < \nu < 200 \text{ GeV}$	50	16	0.086	215	25-38	344	185
H_2 280 GeV	$Q^2 > 2 \text{ GeV}^2$ $40 < \nu < 240 \text{ GeV}$	33	19	0.098	262	25-38	145	94
H_2 280 GeV	$Q^2 > 2 \text{ GeV}^2$ $40 < \nu < 240 \text{ GeV}$	67	15	0.084	230	60-82	151	106
D_2 280 GeV	$Q^2 > 2 \text{ GeV}^2$ $40 < \nu < 240 \text{ GeV}$	160	17	0.094	233	60-82	234	119

Figure Captions

Fig. 1 - The ratios of the proton (antiproton) yield to the overall positive (negative) hadron yield as a function of W^2 .

Fig. 2 - The ratios of the proton (antiproton) yield to the overall positive (negative) hadron yield as a function of z in different W^2 and x_{Bj} intervals. The curves show the Lund Monte Carlo results (dashed: p/h^+ ; full: $\bar{p}/h^-$)

Fig. 3 - The ratio of the proton (antiproton) yield to the overall positive (negative) hadron yield as a function of p_T^2 for
a) $W^2 < 200 \text{ GeV}^2$ b) $W^2 > 200 \text{ GeV}^2$
Curves: Lund Monte Carlo.

Fig. 4 a) the ratio of $\langle p_T^2 \rangle$ of the protons (antiprotons) to $\langle p_T^2 \rangle$ of positive (negative) hadrons as a function of W^2 ;
 b) the ratio between the p_T^2 distributions of associated hadrons in the events containing a proton or an antiproton (class A) and that of associated hadrons in the events containing a pion or a kaon within the proton identification range (class B) (see text).

Fig. 1

Fig. 2

Fig. 3

Fig. 4