ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF-83/28

M. Bonvicini et al. : MEASUREMENT OF FORWARD AND BACKWARD MEAN CHARGED-PERTICLE MULTIPLICITIES IN HIGH-ENERGY (pp) SOFT INTERACTIONS AND COMPARISON WITH HIGH-ENERGY NEUTRINO AND ANTINEUTRINO DEEP INELASTIC SCATTERING

Estratto da:
Lett. Nuovo Cimento 36, 555 (1983)

Servizio Documentazione
dei Laboratori Nazionali di Frascati
Cas. Postale 13 - Frascati (Roma)

LETTERE AL NUOVO CIMENTO VOL. 36, N. 17 23 Aprile 1983

Measurement of Forward and Backward Mean Charged-Particle Multiplicities in High-Energy (pp) Soft Interactions and Comparison with High-Energy Neutrino and Antineutrino Deep Inelastic Scattering.

G. BONVICINI, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, M. CURATOLO
G. D'ALÍ, C. DEL PAPA, B. ESPOSITO, P. GIUSTI, T. MASSAM
R. NANIA, G. SARTORELLI, G. SUSINNO, L. VOTANO and A. ZICHICHI

CERN - Geneva, Switzerland
Istituto di Fisica dell'Università - Bologna, Italia
Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Frascati, Italia
Istituto Nazionale di Fisica Nucleare - Sezione di Bologna, Italia

(ricevuto il 21 Febbraio 1983)

PACS. 13.90. – Other topics in specific reactions and phenomenology of elementary particles.

Summary. – The difference between forward and backward mean charged-particle multiplicities is shown to exist also in (pp) interactions, when these are analysed in analogy with the deep inelastic scattering method. The measurements reported here show that this difference, which has been observed for a long time in (νp) and ($\bar{\nu}$p) deep inelastic scattering experiments, is explained in terms of the omitted correction for the leading effect in the backward hemisphere.

Recently (1) we have proved that high-energy (pp) interactions at low p_T do produce final states with the same average charged-particle multiplicities as (νp) deep inelastic scattering (DIS), provided the (pp) collision is treated as a lepton scattering (2), *i.e.* using the same DIS formalism.

This result follows a series of studies (3-20), which show that there is a close similarity between soft (pp) collisions and (e^+e^-) annihilations.

(1) M. BASILE, G. BONVICINI, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, M. CURATOLO, G. D'ALÍ, C. DEL PAPA, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, G. SUSINNO, L. VOTANO and A. ZICHICHI: *Lett. Nuovo Cimento*, **36**, 303 (1983).
(2) CERN-BOLOGNA GROUP: *Preliminary proposal for a test run on a study of deep-inelastic high-momentum transfer hadronic collisions*, CERN PH I/COM-69/35 (1969).
(3) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, F. PALMONARI, G. SARTORELLI, G. VALENTI and A. ZICHICHI: *Phys. Lett. B*, **92**, 367 (1980).
(4) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO,

The similarity between soft (pp) interactions and the so-called « hard » process, such as (e^+e^-) and DIS, could be established only by introducing a new method for the analysis of (pp) data.

For a detailed description of the method we refer the reader to our previous papers ([1-20]). We only recall here the basic idea: to subtract the leading-particle effects. If (pp) data have to be compared with (e^+e^-), both leading protons need to be sub-

---

P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, G. VALENTI and A. ZICHICHI: *Nuovo Cimento A*, **58**, 193 (1980).

([5]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, G. VALENTI and A. ZICHICHI: *Phys. Lett. B*, **95**, 311 (1980).

([6]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, G. VALENTI and A. ZICHICHI: *Lett. Nuovo Cimento*, **29**, 491 (1980).

([7]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI and A. ZICHICHI: *Phys. Lett. B*, **99**, 247 (1981).

([8]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI and A. ZICHICHI: *Lett. Nuovo Cimento*, **30**, 389 (1981).

([9]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Lett. Nuovo Cimento*, **31**, 273 (1981).

([10]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, V. ROSSI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Nuovo Cimento A*, **65**, 400 (1981).

([11]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, V. ROSSI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Nuovo Cimento A*, **65**, 414 (1981).

([12]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, V. ROSSI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Lett. Nuovo Cimento*, **32**, 210 (1981).

([13]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, V. ROSSI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Nuovo Cimento A*, **66**, 129 (1981).

([14]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, V. ROSSI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Lett. Nuovo Cimento*, **32**, 321 (1981).

([15]) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, V. ROSSI, F. ROHRBACH, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Nuovo Cimento A*, **67**, 53 (1982).

([16]) M. BASILE, G. BONVICINI, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, M. CURATOLO, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, A. PETROSINO, V. ROSSI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Nuovo Cimento A*, **67**, 244 (1982).

([17]) M. BASILE, G. CARA ROMEO L. CIFARELLI, A. CONTIN, M. CURATOLO, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, A. PETROSINO, V. ROSSI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: preprint CERN-EP/81-147 (1981).

([18]) M. BASILE, G. BONVICINI, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, M. CURATOLO, G. D'ALÍ, C. DEL PAPA, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, L. VOTANO and A. ZICHICHI: *Nuovo Cimento A*, **73**, 329 (1983).

([19]) M. BASILE, G. BONVICINI, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, M. CURATOLO, G. D'ALÍ, C. DEL PAPA, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, M. SPINETTI, G. SUSINNO, L. VOTANO and A. ZICHICHI: *Evidence for similarities between charge correlations in soft* (pp) *interactions and* (e^+e^-), in preparation.

([20]) J. BERBIERS, G. BONVICINI, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, M. CURATOLO, G. D'ALÍ, C. DEL PAPA, B. ESPOSITO, P. GIUSTI, T. MASSAM, R. NANIA, G. NATALE, F. PALMONARI, G. SARTORELLI, G. SUSINNO, L. VOTANO and A. ZICHICHI: *Lett. Nuovo Cimento*, **36**, 563 (1983).

tracted out. In fact (e^+e^-) physics has as a key quantity $(\sqrt{s})_{e^+e^-}$, *i.e.* the total (e^+e^-) c.m. energy, to be used for particle production. The quantity which corresponds to $(\sqrt{s})_{e^+e^-}$ in the (pp) interactions is $\sqrt{(q_{\text{total}}^{\text{HAD}})^2}$, *i.e.* the total hadronic energy available for particle production, defined as

$$\sqrt{(q_{\text{total}}^{\text{HAD}})^2} = \sqrt{(q_1^{\text{inc}} - q_1^{\text{leading}} + q_2^{\text{inc}} - q_2^{\text{leading}})^2}\,, \tag{1}$$

where q_1^{inc}, q_2^{inc}, q_1^{leading} and q_2^{leading} are the four-momenta of the two incident protons and of the two leading protons. In fact, in order to get $q_{\text{total}}^{\text{HAD}}$ in a (pp) collision, both leading protons need to be subtracted from the final state. In the case of DIS the basic quantity is W^2; here the leading hadron is included. Therefore, in order to compare (pp) with DIS, we must subtract only one leading proton from the final state (see formula 2).

This is illustrated in fig. 1. In (νp) scattering (fig. 1*a*)), the hadronic system H, obtained by subtracting the muon from the final state, includes the leading proton originating from the target. This is indicated as p^{leading} in fig. 1*a*). In the (pp) case (fig. 1*b*)), one proton is treated similarly to the lepton: p_1^{leading}, coming from the incident proton No. 1, p_1^{inc}, is subtracted out. For the other proton, p_2^{inc}, the leading effect, as in DIS analysis, is ignored. So the hadronic final state H includes the leading proton No. 2, indicated as p_2^{leading} in fig. 1*b*).

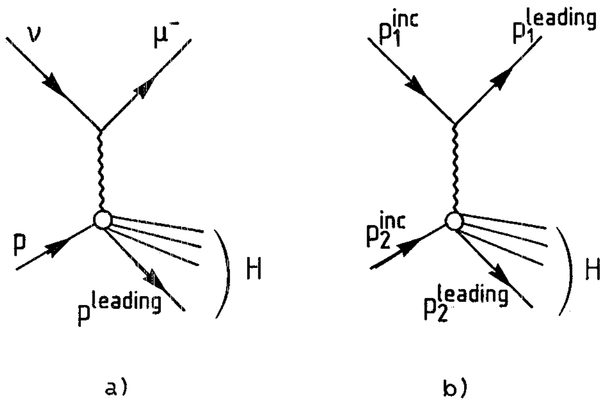

Fig. 1. – *a*) Schematic diagram for $\nu p \to \mu^- + H$. Notice that the leading proton, p^{leading}, is present in the hadronic system H, but it is not subtracted out. *b*) Schematic diagram for $pp \to p_1^{\text{leading}} + H$. Notice that one proton p_1^{leading}, is treated similarly to the « lepton »: its leading effect is subtracted out. The hadronic system H contains p_2^{leading}. However, this leading effect is not subtracted out, in order to follow the same DIS method of analysis.

As mentioned above, we need to use the same variables as in the DIS case. The basic quantity is

$$W^2 = [(q_1^{\text{inc}} - q_1^{\text{leading}}) + q_2^{\text{inc}}]^2\,, \tag{2}$$

where q_1^{inc}, q_2^{inc} and q_1^{leading} are the four-momenta of the two incident protons and of the observed leading proton. The properties of the hadronic system H are therefore studied in terms of W^2. Our previous results ([1]) showed that (pp) interactions do have the same total mean charged-particle multiplicity, $\langle n_{ch} \rangle$, *vs.* W^2, as (νp) DIS processes ([21]).

The purpose of the present paper is to extend such comparison, between (pp) and (νp) DIS, to the study of the forward and backward multiplicities of the hadronic system H: $\langle n_{ch} \rangle_F$, $\langle n_{ch} \rangle_B$. These multiplicities have already been observed, in (νp) ([21]) and ($\bar{\nu}$p) ([22]) DIS experiments, not to be the same. Our point is that the reason for this difference is the omitted correction for the leading-proton effect in DIS experiments. This effect is present in the backward hemisphere of the hadronic system H. We prove this by studying, in (pp) interactions, the hadronic system H, without subtracting the leading proton, as in DIS.

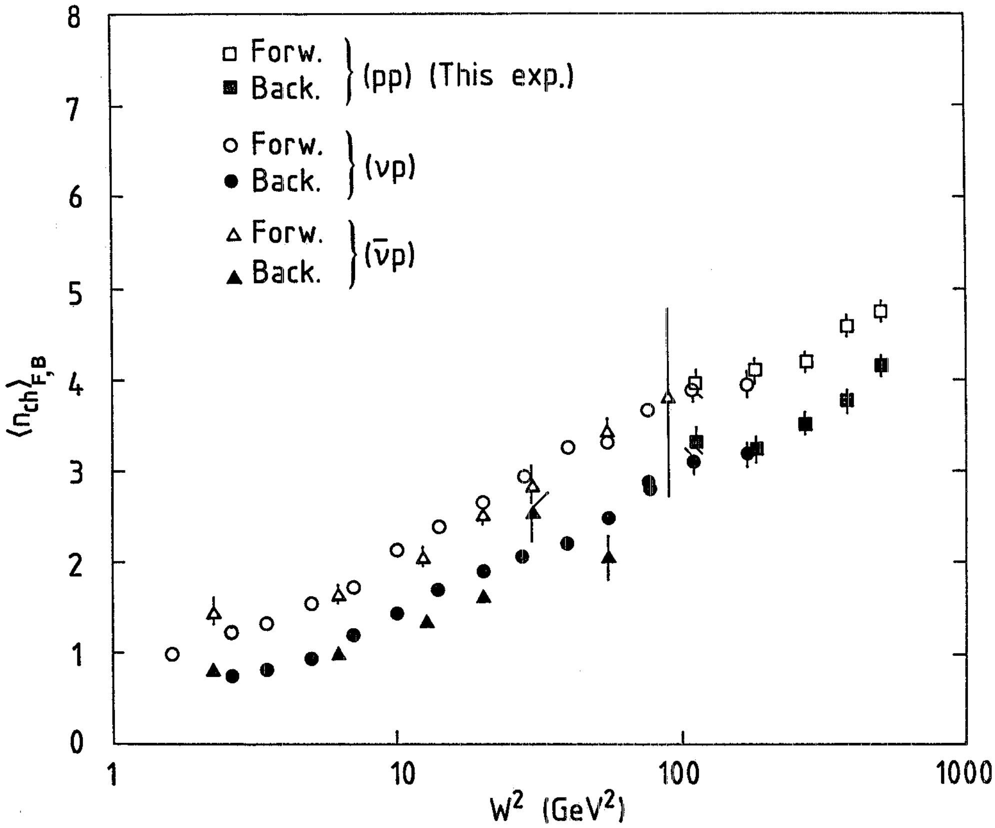

Fig. 2. – The mean charged-particle multiplicities $\langle n_{ch} \rangle_{F,B}$ in the forward and backward hemispheres *vs.* W^2, in (νp), ($\bar{\nu}$p) and (pp) interactions.

([21]) P. ALLEN, J. BLIETSCHAU, H. GRÄSSLER, D. LANCSKE, R. SCHULTE, H. H. SEYFERT, K. BÖCKMANN, C. GEICH-GIMBEL, T. KOKOTT, B. NELLEN, R. PECH, H. SAARIKKO, P. BOSETTI, V. T. COCCONI, B. CONFORTO, A. GRANT, P. O. HULTH, G. KELLNER, D. R. O. MORRISON, R. ORAVA, L. PAPE, P. SCHMID, W. G. SCOTT, H. WACHSMUTH, M. ADERHOLZ, N. SCHMITZ, R. SETTLES, K. L. WERNHARD, W. WITTEK, R. BATLEY, R. GILES, P. GROSSMAN, R. MCGOW, G. MYATT, D. H. PERKINS, D. RADOJICIC, P. RENTON and B. SAITTA: *Nucl. Phys. B*, **181**, 385 (1981).

([22]) M. DERRIK, P. GREGORY, F. LOPINTO, B. MUSGRAVE, J. SCHLERETH, P. SCHREINER, R. SINGER, S. J. BARISH, R. BROCK, A. ENGLER, T. KIKUCHI, R. W. KRAEMER, F. MESSING, B. J. STACEY, M. TABAK, V. E. BARNES, D. D. CARMONY, E. FERNANDEZ, A. F. GARFINKEL and A. T. LAASANEN: *Phys. Rev. D*, **24**, 1071 (1981).

The experiment was performed at the CERN Intersecting Storage Rings (ISR) using the Split Field Magnet (SFM) facility. A detailed description of the apparatus and of data collection can be found elsewhere [10,23].

The results reported here were obtained from 2813 events at $(\sqrt{s})_{pp} = 30$ GeV, selected from a sample of minimum bias events, by requiring only one leading proton detected in the apparatus.

The forward and backward mean charged-particle multiplicities, $\langle n_{ch}\rangle_F$ and $\langle n_{ch}\rangle_B$, of the hadronic system H have been measured. The forward and backward hemispheres are defined in the c.m. of the hadronic system H, the forward hemisphere being that where the momentum transferred by the proton No. 1 is. Notice that this is the proton which is treated in the same way as the lepton is DIS.

The results are shown in fig. 2 as a function of W^2. In the same plot the results from (νp) [21] and ($\bar{\nu}$p) [22] DIS experiments are reported for comparison. Our data do reproduce the effects already found in (νp) and ($\bar{\nu}$p) DIS experiments.

This agreement shows that the forward-backward differences in the mean charged multiplicities, are explained in terms of the omitted correction for the leading-proton effects in the backward hemisphere.

Therefore, if (νp) and ($\bar{\nu}$p) DIS data are analysed by removing the leading-proton effects, the multiplicities in the two new hemispheres (*) «forward» and «backward» will be the same.

---

(23) R. Bouclier, R. C. A. Brown, E. Chesi, L. Dumps, H. G. Fischer, P. G. Innocenti, G. Maurin, A. Minten, L. Naumann, F. Piuz and O. Ullaland: *Nucl. Instrum. Methods*, **125**, 19 (1975).

(*) Recently one of the groups working on (νp) DIS experiments has calculated corrections to apply to the observed forward and backward charged-particle multiplicities [24]. Once these corrections are applied, the differences between the forward and backward multiplicities, as defined in DIS, almost disappear. This is a peculiar result, because in lepton-hadron DIS processes such as (νp) and ($\bar{\nu}$p), the leading hadron is present in the backward hemisphere [14], therefore the forward multiplicity, as defined in DIS, is expected to be larger than the backward one.

(24) ABCMO Collaboration (BEBC WA21): Contributed paper No. 712, *Multiplicities of secondary hadrons produced in* (νp) *and* ($\bar{\nu}$p) *charged-current interactions, XXI International Conference on High Energy Physics, Paris 1982.*