

ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

LNF -81/73

M. Basile et al. :
CHARGED-PARTICLE MULTIPLICITIES IN pp INTERACTIONS
AND COMPARISON WITH e^+e^- DATA

Estratto da :

Nuovo Cimento 65A, 400 (1981)

Charged-Particle Multiplicities in pp Interactions and Comparison with e^+e^- Data.

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

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

Istituto di Fisica dell'Università - Perugia, Italia

Istituto di Fisica dell'Università - Roma, Italia

(ricevuto il 24 Luglio 1981)

Summary. — By using three different c.m. energies in pp interactions, $\sqrt{s} = 30, 44, 62$ GeV, it is shown that the average charged-particle multiplicity $\langle n_{ch} \rangle$ scales with \sqrt{s} once the correct hadronic energy available for multiparticle production, E_{had} , is used as basic parameter. The pp data, analysed in this way, are compared with e^+e^- data at equivalent energies. The agreement is very satisfactory.

1. — Introduction.

We have already reported ⁽¹⁾ a measurement of the average charged-particle multiplicity $\langle n_{ch} \rangle$ in pp interactions at $(\sqrt{s})_{pp} = 62$ GeV total c.m. energy.

⁽¹⁾ 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).

The key point of this experiment was to show that the energy available for particle production in a pp interaction is not the total c.m. energy \sqrt{s} . In fact, in such an interaction a large fraction of energy can be carried away by the «leading» proton. In order to know the correct energy available for particle production in a pp interaction, it is crucial to know the difference between the incident-proton energy E_{inc} and the leading-proton energy E_{lead} , *i.e.*

$$E_{\text{had}} = E_{\text{inc}} - E_{\text{lead}}.$$

It is this quantity E_{had} which is taken ⁽¹⁻⁷⁾ as a parameter to establish the correct energy level available in a pp interaction. Once this is done, the values of $\langle n_{\text{ch}} \rangle$ measured in pp interactions are found to be in excellent agreement with the values of $\langle n_{\text{ch}} \rangle$ measured in e^+e^- annihilations at the same equivalent energy, *i.e.*

$$2E_{\text{had}} = 2E_{\text{beam}}^{e^+e^-} = (\sqrt{s})_{e^+e^-}.$$

It is evident that different E_{inc} can produce the same E_{had} . The crucial point is to show that equal E_{had} values, obtained from different E_{inc} , produce the same $\langle n_{\text{ch}} \rangle$.

2. - Data analysis and results.

Purpose of the present paper is to report on an experiment performed at the CERN ISR to check this point.

(2) 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).

(3) 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: *Nuovo Cimento A*, **58**, 193 (1980).

(4) 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).

(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, M. SPINETTI, G. SUSINNO, G. VALENTI and A. ZICHICHI: *Phys. Lett. B*, **99**, 247 (1981).

(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, M. SPINETTI, G. SUSINNO, G. VALENTI, L. VOTANO and A. ZICHICHI: *Lett. Nuovo Cimento*, **30**, 389 (1981).

(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, L. VOTANO and A. ZICHICHI: *Lett. Nuovo Cimento*, **31**, 273 (1981).

The experiment was done using the Split-Field Magnet (SFM) and its powerful multiwire proportional chamber (MWPC) assembly⁽⁸⁾. For details on the experimental set-up and on the data analysis, we refer the reader to our previous works⁽¹⁻⁷⁾. The total number of events fully reconstructed with one leading proton is 21 394, of which 3705 were at $E_{\text{inc}} = 15$ GeV, 11 689 at $E_{\text{inc}} = 22$ GeV and 6000 at $E_{\text{inc}} = 31$ GeV.

In addition to these data, where the trigger was chosen in order to enrich the sample of events with at least one « leading » proton, we have also analysed ~ 18810 events taken earlier at $\sqrt{s} = 62$ GeV in the « minimum bias » trigger mode (old data). The comparison of the data at the same $E_{\text{inc}} = 31$ GeV (*i.e.* $\sqrt{s} = 62$ GeV), taken with two different « trigger » conditions, is made in order to be sure that the trigger used to enrich the events with a « leading » proton produce the same results as the « minimum bias » trigger. In fact, our first evidence that multiparticle production processes in pp interactions were showing remarkable similarities with the e^+e^- annihilations was based on the « minimum bias » trigger events⁽¹⁾. In that experiment the « leading » proton sample was obtained via a software analysis. In order to improve data-taking efficiency, in the present experiment we have introduced the « leading » proton condition at the « hard » trigger level. However, it had to be proved that this new way of operating the SFM does not introduce any bias.

As mentioned above, three incident ISR proton energies were used:

$$E_{\text{inc}} = 15 \text{ GeV} ,$$

$$E_{\text{inc}} = 22 \text{ GeV} ,$$

$$E_{\text{inc}} = 31 \text{ GeV} .$$

Each energy corresponds to a given range of E_{had} values, as shown in fig. 1. These E_{had} value ranges are determined by the choice of fractional momentum $x_{\text{F}} = 2p_{\text{L}}/\sqrt{s}$,

$$0.35 \leq x_{\text{F}} \leq 0.86 ,$$

needed to identify the « leading » proton, as explained in our previous papers⁽¹⁻⁷⁾.

The charged multiplicity has been measured by counting the tracks in the same hemisphere as that of the leading proton, without any cut in momentum resolution. The observed multiplicities have been corrected for detection efficiency via Monte Carlo simulation. This correction is, on the average, less than 30%, and introduces a systematic error $\leq 5\%$ amongst the four sets of data, and an overall systematic uncertainty $\leq 8\%$.

⁽⁸⁾ 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).

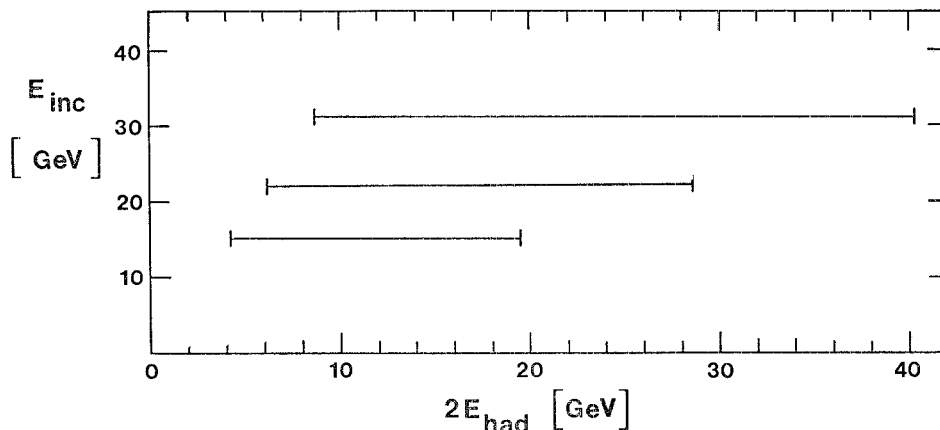


Fig. 1. - $2E_{\text{had}}$ range corresponding to each incident energy E_{inc} . Notice the overlap region in which different E_{inc} produce the same $2E_{\text{had}}$ values. The range of $2E_{\text{had}}$ at each E_{inc} is determined by the α_F values chosen to identify the «leading» proton.

As mentioned above, the basic point of our present study was to repeat the experiment at three different energies which correspond to $\sqrt{s} = 30, 44$ and 62 GeV.

The latter value was repeated in order to check that this new experiment at $\sqrt{s} = 62$ GeV reproduces the same «old» $\sqrt{s} = 62$ GeV data. Table I shows the results at these energies, including the «old data». An inspection of these data shows that equal values of $2E_{\text{had}}$ obtained from different \sqrt{s} produce, within the experimental limits of uncertainty, the same values of $\langle n_{\text{ch}} \rangle$.

This equality answers the main problem of our present investigation.

The data, averaged for each value of $2E_{\text{had}}$, are presented in fig. 2 together with e^+e^- data from ADONE, SPEAR and PETRA ⁽⁹⁻¹¹⁾. A contamination

⁽⁹⁾ PLUTO COLLABORATION (C. BERGER *et al.*): *Phys. Lett. B*, **95**, 313 (1980).

⁽¹⁰⁾ C. BACCI, G. DE ZORZI, G. PENSO, B. STELLA, D. BOLLINI, R. BALDINI CELIO, G. BATTISTONI, G. CAPON, R. DEL FABBRO, E. IAROCCHI, M. M. MASSAI, S. MORIGGI, G. P. MURTAS, M. SPINETTI and L. TRASATTI: *Phys. Lett. B*, **86**, 234 (1979). For these very-low-energy data, the contribution of K_S^0 decay is negligible.

⁽¹¹⁾ J. L. SIEGRIST: Ph. D. Thesis, SLAC-Report No. 225 (1979). These data are corrected for K_S^0 contributions using data of V. LÜTH, F. M. PIERRE, G. S. ABRAMS, M. S. ALAM, A. M. BOYARSKI, M. BREIDENBACH, W. CHINOWSKY, J. DORFAN, G. J. FELDMAN, G. GOLDHABER, G. HANSON, J. A. JAROS, J. A. KADYK, R. R. LARSEN, A. LITKE, D. LÜKE, H. L. LYNCH, R. J. MADARAS, H. K. NGUYEN, J. M. PATERSON, M. L. PERL, I. PERUZZI, CH. PEYROU, M. PICCOLO, T. P. PUN, P. RAPIDIS, B. RICHTER, B. SADOULET, R. H. SCHINDLER, R. H. SCHWITTERS, J. SIEGRIST, W. TANENBAUM, G. H. TRILLING, F. VANNUCCI, J. S. WHITAKER and J. E. WISS: *Phys. Lett. B*, **70**, 120 (1977).

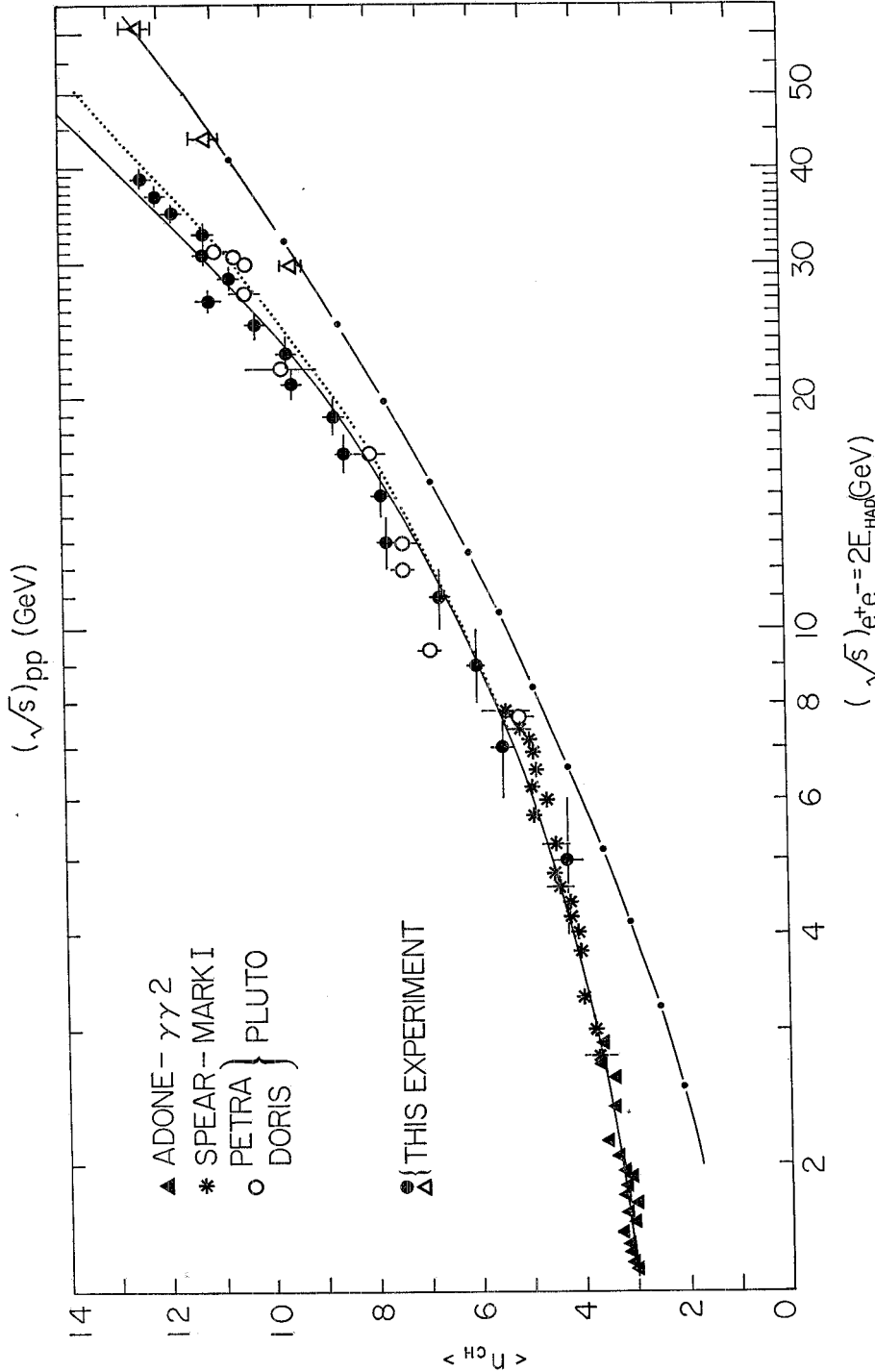


Fig. 2. - Mean charged multiplicity averaged over different \sqrt{s} vs. $2E_{had}$ compared with e^+e^- data. The contribution of $K_S^0 \rightarrow \pi^+\pi^-$ has been subtracted (ref. (11)). Each value is an average over 2 GeV. The quoted errors are statistical only. The systematic uncertainty is less than 8%. The continuous line is the best fit to our data together with ADONE (10) and SPEAR (11) data, according to the formula $\langle n_{ch} \rangle = a + b \exp [c \sqrt{\ln (s/A^2)}]$ (14-16). The dotted line is the best fit using PLUTO data (9) instead of our data. The dashed-dotted line is the pp total charged multiplicity (13,17). For this curve, the abscissa is $(\sqrt{s})_{pp}$. The triangular points in this curve are our data.

TABLE I. — Mean charged multiplicity vs. $2E_{\text{had}}$ for different \sqrt{s} of the ISR. The values, relative to a single hemisphere in pp interaction, are already multiplied by 2 in order to allow a comparison with e^+e^- data that are relative to the full event. The quoted errors are statistical only. The systematic uncertainty is estimated to be less than 8%.

$2E_{\text{had}}$ (GeV)	\sqrt{s}				
	30 GeV	44 GeV	62 GeV	62 GeV (old data)	Average
5	4.3 ± 0.3	—	—	—	4.3 ± 0.3
7	5.5 ± 0.3	5.5 ± 0.2	—	—	5.5 ± 0.2
9	5.6 ± 0.2	6.4 ± 0.2	6.1 ± 0.4	5.8 ± 0.4	6.0 ± 0.15
11	6.4 ± 0.3	6.7 ± 0.2	7.3 ± 0.4	6.9 ± 0.4	6.7 ± 0.15
13	7.7 ± 0.3	7.7 ± 0.2	7.6 ± 0.4	7.4 ± 0.4	7.7 ± 0.15
15	7.4 ± 0.3	7.8 ± 0.2	8.1 ± 0.4	7.9 ± 0.3	7.8 ± 0.15
17	8.4 ± 0.3	8.3 ± 0.2	8.9 ± 0.4	8.9 ± 0.3	8.5 ± 0.15
19	8.6 ± 0.3	8.2 ± 0.3	9.6 ± 0.4	8.8 ± 0.3	8.7 ± 0.2
21	—	9.0 ± 0.3	9.9 ± 0.4	9.7 ± 0.3	9.5 ± 0.2
23	—	9.2 ± 0.3	9.9 ± 0.4	9.9 ± 0.3	9.6 ± 0.2
25	—	9.9 ± 0.3	10.8 ± 0.4	10.3 ± 0.3	10.2 ± 0.2
27	—	—	10.8 ± 0.4	11.3 ± 0.3	11.1 ± 0.25
29	—	—	11.2 ± 0.4	10.4 ± 0.3	10.7 ± 0.2
31	—	—	11.2 ± 0.3	11.2 ± 0.3	11.2 ± 0.2
33	—	—	11.4 ± 0.3	11.2 ± 0.3	11.2 ± 0.2
35	—	—	12.0 ± 0.3	11.7 ± 0.3	11.8 ± 0.2
37	—	—	11.8 ± 0.3	12.4 ± 0.3	12.1 ± 0.2
39	—	—	12.6 ± 0.3	12.3 ± 0.3	12.4 ± 0.2

from the $K_s^0 \rightarrow \pi^+\pi^-$ decay has been evaluated, from existing data (¹²⁻¹³), to be about 4% and has been subtracted. Other small contaminations, such as γ conversion, have also been evaluated and subtracted. The effect of the misidentification of leading protons has been studied via Monte Carlo simulation (*): it turns out that the maximum effect for the highest E_{had} value is 2%.

The agreement shown in fig. 2 between pp and e^+e^- data is very satisfactory. In this figure the «standard» $\langle n_{\text{ch}} \rangle$ vs. \sqrt{s} in pp interactions is also reported for reference.

(¹²) G. GIACOMELLI and M. JACOB: *Phys. Rep.*, **55**, 1 (1979), and references therein.

(¹³) W. THOMÉ, K. EGGERT, K. GIBONI, H. LISKEN, P. DARRIULAT, P. DITTMANN, M. HOLDER, K. T. McDONALD, H. ALBRECHT, T. MODIS, K. TITTEL, H. PREISSNER, P. ALLEN, I. DERADO, V. ECKARDT, H.-J. GEBAUER, R. MEINKE, P. SEYBOTH and S. UHLIG: *Nucl. Phys. B*, **129**, 365 (1977).

(*) Invariant-phase-space Monte Carlo with limited p_{T} .

The agreement between pp and e^+e^- data can be expressed in a quantitative way with the best fit. The continuous line in fig. 2 is the best fit to our data together with ADONE⁽¹⁰⁾ and SPEAR⁽¹¹⁾ data. The dotted line is the best fit to the e^+e^- data. The two curves are in excellent agreement.

The results of the best fit to our pp data have been obtained by using the following analytic form⁽¹⁴⁻¹⁶⁾:

$$\langle n_{\text{ch}} \rangle = a + b \exp [c \sqrt{\ln(s/\Lambda^2)}],$$

where Λ has been set at $\Lambda = 0.5$ GeV. The best fit gives the following values for the parameters:

$$a = 2.47 \pm 0.06,$$

$$b = 0.030 \pm 0.004,$$

$$c = 1.97 \pm 0.05,$$

with $\chi^2/\text{DOF} = 1.7$.

In table II the inclusive values of $\langle n_{\text{ch}} \rangle$, as measured in our experiment with the three values of \sqrt{s} , are reported. These data are in excellent agreement with well-known results^(13,17) on pp interactions and show that, if we analyse $\langle n_{\text{ch}} \rangle$ in the usual way, we get the same results as other experiments do. Our data fit well in the standard pp curve as shown in fig. 2. This is an important self-consistency check.

TABLE II. — Total charged multiplicities $\langle n_{\text{ch}} \rangle$ for the minimum-bias samples vs. \sqrt{s} of the ISR. The quoted errors are statistical only. The systematic uncertainty is estimated to be less than 8%.

\sqrt{s} (GeV)	$\langle n_{\text{ch}} \rangle$
30.0	9.4 ± 0.2
44.0	11.1 ± 0.3
62.0	12.4 ± 0.3

3. — Conclusions.

The results of the present experiment show that the average charged-particle multiplicity produced in e^+e^- annihilations is in good agreement with the values measured in pp interactions, once the correct hadronic energy E_{had}

⁽¹⁴⁾ A. BASSETTO, M. CIAFALONI and G. MARCHESINI: *Phys. Lett. B*, **83**, 207 (1979).

⁽¹⁵⁾ W. FURMANSKI, R. PETRONZIO and S. POKORSKI: *Nucl. Phys. B*, **155**, 253 (1979).

⁽¹⁶⁾ A. BASSETTO, M. CIAFALONI and G. MARCHESINI: *Nucl. Phys. B*, **163**, 477 (1980).

⁽¹⁷⁾ E. ALBINI, P. CAPILUPPI, G. GIACOMELLI and A. M. ROSSI: *Nuovo Cimento A*, **32**, 101 (1976).

available for multiparticle production is determined. The average charged-particle multiplicity $\langle n_{\text{ch}} \rangle$ scales, as expected, with the total c.m. pp energy. In fact, different $(\sqrt{s})_{\text{pp}}$ can produce the same E_{had} and the same E_{had} produces the same average charged-particle multiplicity. This has been proved using three different $(\sqrt{s})_{\text{pp}}$, *i.e.* 30, 44, 62 GeV.

● RIASSUNTO

La molteplicità media carica $\langle n_{\text{ch}} \rangle$ delle interazioni protone-protone è studiata a tre diverse energie nel centro di massa ($\sqrt{s} = 30, 44, 62$ GeV). La molteplicità $\langle n_{\text{ch}} \rangle$ mostra un effetto di «scaling» con \sqrt{s} , se analizzata in funzione del parametro E_{had} , l'energia adronica disponibile per la produzione di particelle. I dati di interazioni pp, analizzati in questo modo, sono confrontati con i dati di e^+e^- ad energia equivalente: ne risulta un ottimo accordo.

Множественность заряженных частиц в pp взаимодействиях и сравнение с e^+e^- данными.

Резюме (*). — Используя три различных энергии в системе центра масс при pp взаимодействиях, $\sqrt{s} = 30, 44, 62$ ГэВ, показывается, что средняя множественность заряженных частиц $\langle n_{\text{ch}} \rangle$ изменяется в соответствии с \sqrt{s} , тогда как энергия адронов, доступная для множественного рождения частиц, E_{had} , используется как основной параметр. Полученные pp данные сравниваются с e^+e^- данными при эквивалентных энергиях. Получается удовлетворительное согласие.

(* *Переведено редакцией.*)

M. BASILE, <i>et al.</i> 1 Ottobre 1981 <i>Il Nuovo Cimento</i> Serie 11, Vol. 65 A, pag. 400-407
--