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M. Basile et al. : A DETAILED STUDY OF $\langle n_{ch} \rangle$ vs. E^{had}
AND $m_{1,2}$ AT DIFFERENT ($\sqrt{s}$)$_{pp}$ IN (pp) INTERACTIONS

A Detailed Study of $\langle n_{ch} \rangle$ vs. E^{had} and $m_{1,2}$ at Different $(\sqrt{s})_{pp}$ in (pp) Interactions.

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Summary. — By using (pp) interactions at three different c.m. energies, $(\sqrt{s})_{pp} = 30, 44, 62$ GeV, it is shown that the average charged-particle multiplicity $\langle n_{ch} \rangle$ vs. the invariant mass of the hadronic system $m_{1,2}$ has the same behaviour as it has vs. $2E^{had}$. Moreover, in both cases $\langle n_{ch} \rangle$ is shown to be nearly independent of $(\sqrt{s})_{pp}$ and in good agreement with the average charged-particle multiplicity measured in the (e⁺e⁻) annihilation.

1. – Introduction and purpose of the experiment.

We have already reported on a measurement of the average charged-particle multiplicity $\langle n_{ch} \rangle$ in (pp) interactions at $(\sqrt{s})_{pp} = 30, 44$ and 62 GeV total c.m. energies [1]. The value of $\langle n_{ch} \rangle$ was measured as a function of E^{had},

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(1) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE,

the energy available for particle production, once the energy carried away by the «leading» outgoing proton is subtracted. For fixed values of E^{had}, $\langle n_{\text{ch}} \rangle$ was found to be independent of $(\sqrt{s})_{\text{pp}}$. Moreover, the behaviour of $\langle n_{\text{ch}} \rangle$ vs. $2E^{\text{had}}$ was found to be in good agreement with the results obtained in (e^+e^-) annihilation, when $2E^{\text{had}} = (\sqrt{s})_{e^+e^-}$.

In our analysis of (pp) collisions we have already introduced [2] the quantity $m_{1,2}$, which is

(1)
$$m_{1,2} = [(E_1^{\text{had}} + E_2^{\text{had}})^2 - (\boldsymbol{p}_1^{\text{had}} + \boldsymbol{p}_2^{\text{had}})^2]^{\frac{1}{2}},$$

where E_1^{had}, $\boldsymbol{p}_1^{\text{had}}$ and E_2^{had}, $\boldsymbol{p}_2^{\text{had}}$ are the energy and momentum differences between the incident protons and the outgoing leading protons in the two hemispheres [3-8]. The quantity $m_{1,2}$ represents the invariant mass of the whole hadronic system which remains once the two outgoing leading protons are subtracted.

The purpose of the present work is to see whether $\langle n_{\text{ch}} \rangle$ vs. $m_{1,2}$ has the same behaviour as when it is studied in terms of E^{had}. In this case it had to scale with $(\sqrt{s})_{\text{pp}}$ and it had to be in good agreement with e^+e^- data when $2E_{\text{beam}}^{e^+,e^-} = 2E^{\text{had}} = m_{1,2}$. Moreover, it is important to study whether $\langle n_{\text{ch}} \rangle$ vs. $m_{1,2}$ depends on the selection of given values of E^{had}, and also whether $\langle n_{\text{ch}} \rangle$ vs. E^{had} depends on any selection of $m_{1,2}$ values.

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).

[2] 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).

[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, P. GIUSTI, T. MASSAM, R. NANIA, F. PALMONARI, G. SARTORELLI, G. VALENTI and A. ZICHICHI: Phys. Lett. B, 95, 311 (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: Nuovo Cimento A, 58, 193 (1980).

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[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: Lett. Nuovo Cimento, 30, 389 (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, G. VALENTI and A. ZICHICHI: Lett. Nuovo Cimento, 31, 273 (1981).

2. – Data analysis and results.

The experiment was done at the CERN Intersecting Storage Rings (ISR) using the Split-Field Magnet (SFM) and its powerful multiwire proportional chamber (MWPC) assembly [9]. For details of the experimental set-up and
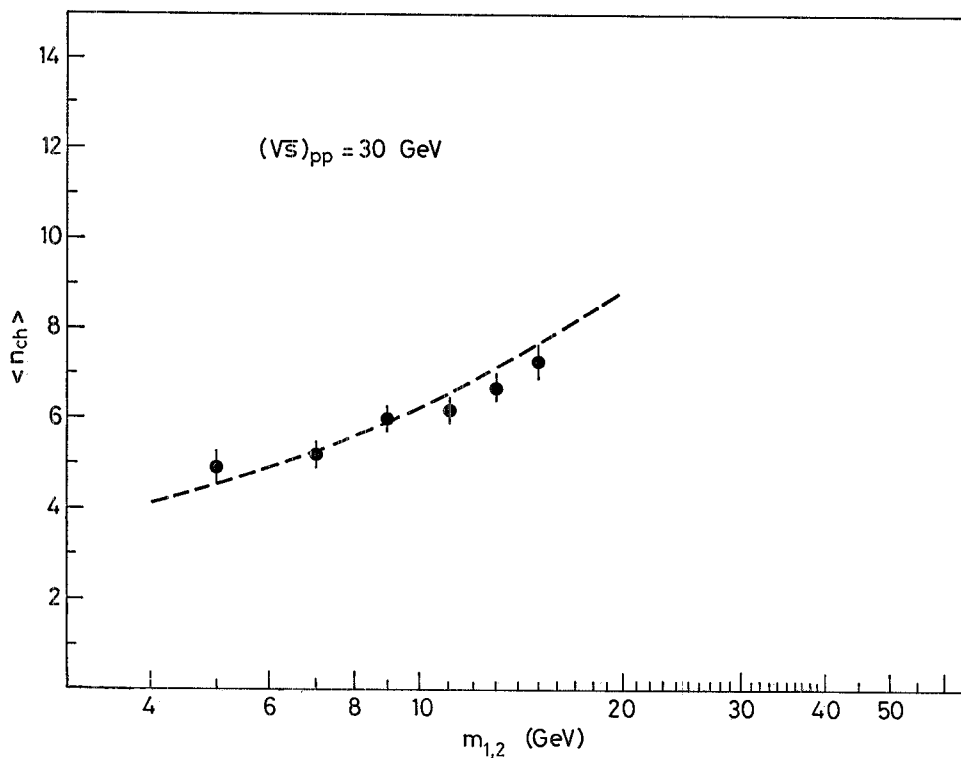

Fig. 1. – Mean charged-particle multiplicity $\langle n_{\mathrm{ch}} \rangle$ vs. $m_{1,2}$ at $(\sqrt{s})_{pp} = 30$ GeV. The dashed line is our previously published fit [1].

data analysis, we refer the reader to our previous papers [1-8]. The total number of selected events with two leading protons, one in each hemisphere, with x_{F} ($x_{\mathrm{F}} = 2p_{\mathrm{L}}/\sqrt{s}$, where p_{L} is the longitudinal proton momentum) in the range

$$(2) \qquad\qquad 0.42 \leqslant x_{\mathrm{F}} \leqslant 0.86$$

[9] R. BOUCLIER, R. C. A. BROWN, E. CHESI, L. DUMPS, H. G. FISCHER, P. G. INNO-CENTI, G. MAURIN, A. MINTEN, L. NAUMANN, F. PIUZ and O. ULLALAND: Nucl. Instrum. Methods, **125**, 19 (1975).

is 9850, of which 1490 are collected at $(\sqrt{s})_{pp} = 30$ GeV, 5260 at $(\sqrt{s})_{pp} = 44$ GeV and 3100 at $(\sqrt{s})_{pp} = 62$ GeV. In addition to these data, in which the trigger was chosen such that it would enrich the samples with two leading protons, we have also analysed 1150 events at $(\sqrt{s})_{pp} = 62$ GeV, taken earlier in the « minimum bias » trigger mode (we will call this sample the « old data ») [1].
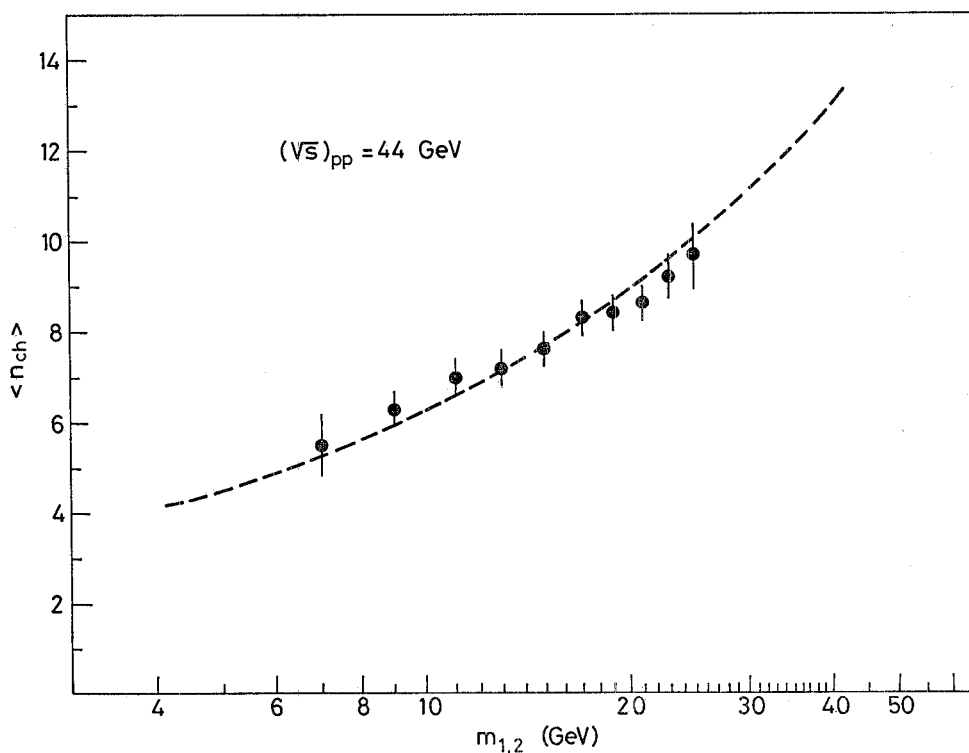

Fig. 2. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $m_{1,2}$ at $(\sqrt{s})_{pp} = 44$ GeV. The dashed line is our previously published fit [1].

The charged-particle multiplicity has been measured by counting the tracks in the whole event, 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 $\lesssim 5\%$ amongst the four sets of data and an overall systematic uncertainty $\lesssim 8\%$.

The contribution to $\langle n_{ch} \rangle$ due to $K_S^0 \to \pi^+\pi^-$ has been subtracted. Other small contributions, such as γ conversion, have also been subtracted.

Since protons are not directly identified, there is a contamination from positive pions. In the selected range of x_F (eq. (2)) this contamination varies

TABLE I. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $2E^{had}$ and $m_{1,2}$ for different $(\sqrt{s})_{pp}$ of the ISR. In both cases events with two leading protons, one for each hemisphere, have been used. The quoted errors are statistical only. The systematic uncertainty is estimated to be less than 8%.

$\langle n_{ch} \rangle$ vs. $2E^{had}$

$2E^{had}$ (GeV)	$(\sqrt{s})_{pp}$				
	30 GeV	44 GeV	62 GeV	62 GeV «old data»	Average
5	4.4 ± 0.3				4.4 ± 0.3
7	5.3 ± 0.3	5.4 ± 0.3			5.4 ± 0.2
9	5.3 ± 0.3	6.3 ± 0.3	6.6 ± 0.5		6.1 ± 0.2
11	6.2 ± 0.3	6.7 ± 0.3	7.5 ± 0.5		6.7 ± 0.2
13	7.6 ± 0.3	7.4 ± 0.3	7.8 ± 0.5	8.1 ± 1.0	7.7 ± 0.2
15	7.1 ± 0.3	7.8 ± 0.3	8.0 ± 0.5		7.6 ± 0.2
17	8.1 ± 0.4	8.2 ± 0.3	9.4 ± 0.5	8.2 ± 1.0	8.4 ± 0.3
19		8.0 ± 0.3	9.4 ± 0.5		8.5 ± 0.3
21		9.0 ± 0.3	9.5 ± 0.5		9.2 ± 0.3
23		8.9 ± 0.3	10.2 ± 0.5	9.0 ± 0.6	9.5 ± 0.3
25		10.0 ± 0.4	10.8 ± 0.5		10.3 ± 0.4
27			11.1 ± 0.5	10.3 ± 0.7	10.9 ± 0.5
29			11.1 ± 0.5		11.0 ± 0.5
31			11.3 ± 0.5		11.1 ± 0.5
33			11.1 ± 0.5	10.8 ± 0.5	11.0 ± 0.5
35			11.7 ± 0.5		11.7 ± 0.5

$\langle n_{ch} \rangle$ vs. $m_{1,2}$

$m_{1,2}$ (GeV)	$(\sqrt{s})_{pp}$				
	30 GeV	44 GeV	62 GeV	62 GeV «old data»	Average
5	4.9 ± 0.4				4.9 ± 0.4
7	5.2 ± 0.3	5.5 ± 0.7			5.3 ± 0.3
9	6.0 ± 0.3	6.3 ± 0.4			6.2 ± 0.3
11	6.2 ± 0.3	7.0 ± 0.4	7.8 ± 0.8		6.8 ± 0.3
13	6.7 ± 0.3	7.2 ± 0.4	7.5 ± 0.7	7.3 ± 1.0	7.1 ± 0.3
15	7.3 ± 0.4	7.6 ± 0.4	9.1 ± 0.6		7.8 ± 0.3
17		8.3 ± 0.4	8.9 ± 0.5	9.1 ± 0.7	8.6 ± 0.4
19		8.4 ± 0.4	9.4 ± 0.5		8.8 ± 0.4
21		8.6 ± 0.4	9.8 ± 0.5		9.1 ± 0.4
23		9.2 ± 0.5	9.9 ± 0.5	9.9 ± 0.6	9.6 ± 0.4
25		9.7 ± 0.8	10.4 ± 0.4		10.2 ± 0.4
27			10.6 ± 0.4	9.8 ± 0.6	10.4 ± 0.4
29			11.1 ± 0.5		11.0 ± 0.5
31			11.8 ± 0.5		11.7 ± 0.5
33			11.2 ± 0.6	10.7 ± 0.7	11.2 ± 0.6
35			11.9 ± 0.6		11.9 ± 0.6

from 25 % to 2 % ([10]). This misidentification has been studied via a p_T-limited phase-space Monte Carlo and produces a change in $\langle n_{ch} \rangle$ of about 0.5 charged unit at the highest $m_{1,2}$.

In table I and in fig. 1 to 4, the values of $\langle n_{ch} \rangle$ as a function of $m_{1,2}$ are reported for the three values $(\sqrt{s})_{pp} = 30$, 44 and 62 GeV. There is a good
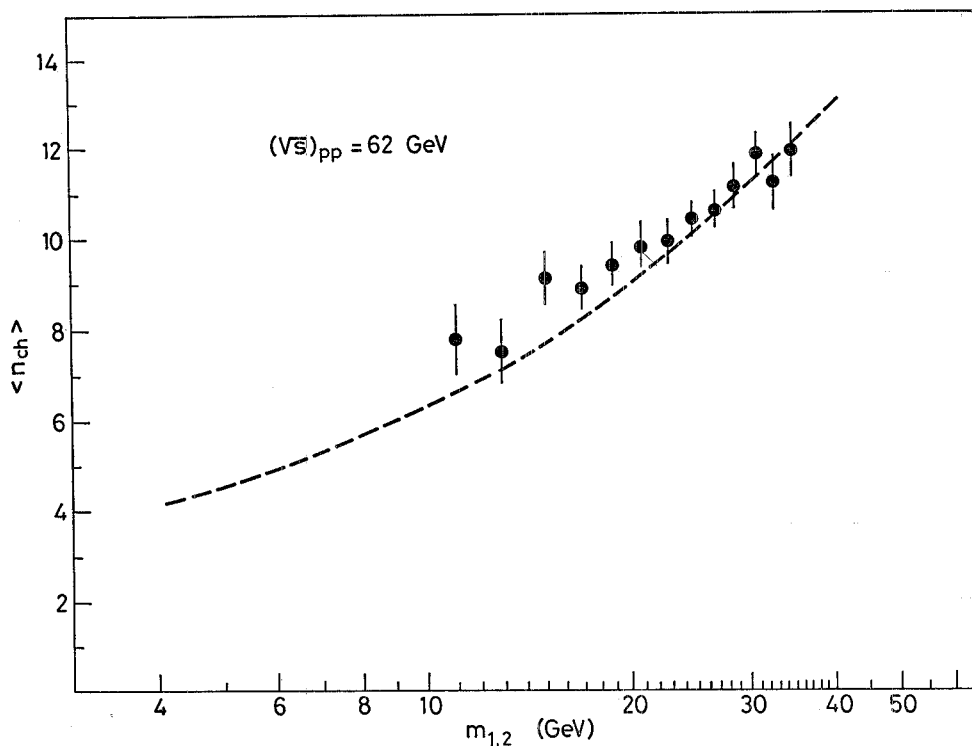

Fig. 3. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $m_{1,2}$ at $(\sqrt{s})_{pp} = 62$ GeV. The dashed line is our previously published fit ([1]).

agreement with our previously published ([1]) best fit to $\langle n_{ch} \rangle$ vs. E^{had} (dashed line). These data show that, within the experimental uncertainties, $\langle n_{ch} \rangle$ vs. $m_{1,2}$ nearly scales with $(\sqrt{s})_{pp}$. In table I the values of $\langle n_{ch} \rangle$, averaged at a given value of $m_{1,2}$ or $2E^{had}$ over the different $(\sqrt{s})_{pp}$ samples, are reported. These data are shown in fig. 5 and 6. The agreement with the e+e− data, as

([10]) P. CAPILUPPI, G. GIACOMELLI, A. M. ROSSI, G. VANNINI and A. BUSSIÈRE: Nucl. Phys. B, 70, 1 (1974); P. CAPILUPPI, G. GIACOMELLI, A. M. ROSSI, G. VANNINI, A. BERTIN, A. BUSSIÈRE and R. J. ELLIS: Nucl. Phys. B, 79, 189 (1974).

well as with our already published data [1], is excellent. This can be deduced from the dashed lines which simultaneously fit our data and the (e^+e^-) data.

We now report on the detailed study of $\langle n_{ch} \rangle$ vs. $m_{1,2}$ and $2E^{had}$.

As a first test we have studied the influence of the quantity E^{had} on $\langle n_{ch} \rangle$ vs. $m_{1,2}$. For this purpose, two samples of events were selected:
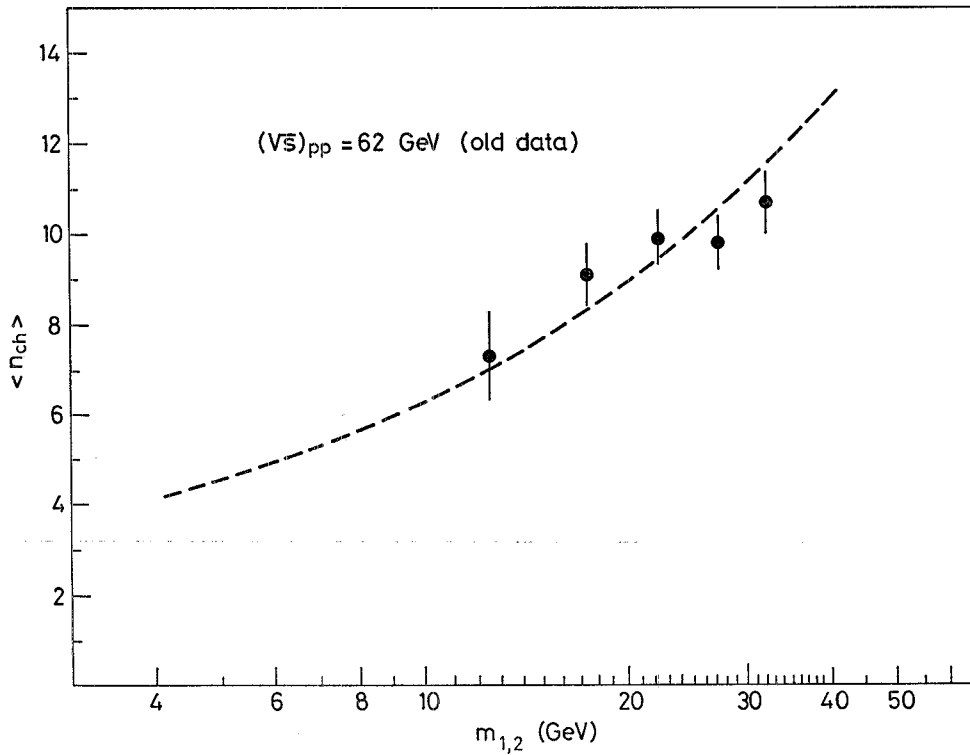

Fig. 4. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $m_{1,2}$ at $(\sqrt{s})_{pp} = 62$ GeV by using the « old data » sample. The dashed line is our previously published fit [1].

i) events whose $m_{1,2}$ is obtained by combining nearly equal values of E^{had}

$$\{ |(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| \leqslant 15 \% \} \, ;$$

ii) events whose $m_{1,2}$ is obtained by combining very different values of E^{had}

$$\{ |(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| \geqslant 35 \% \} \, .$$

The values of $\langle n_{ch} \rangle$ vs. $m_{1,2}$ for these two samples are shown in fig. 7a) and b).
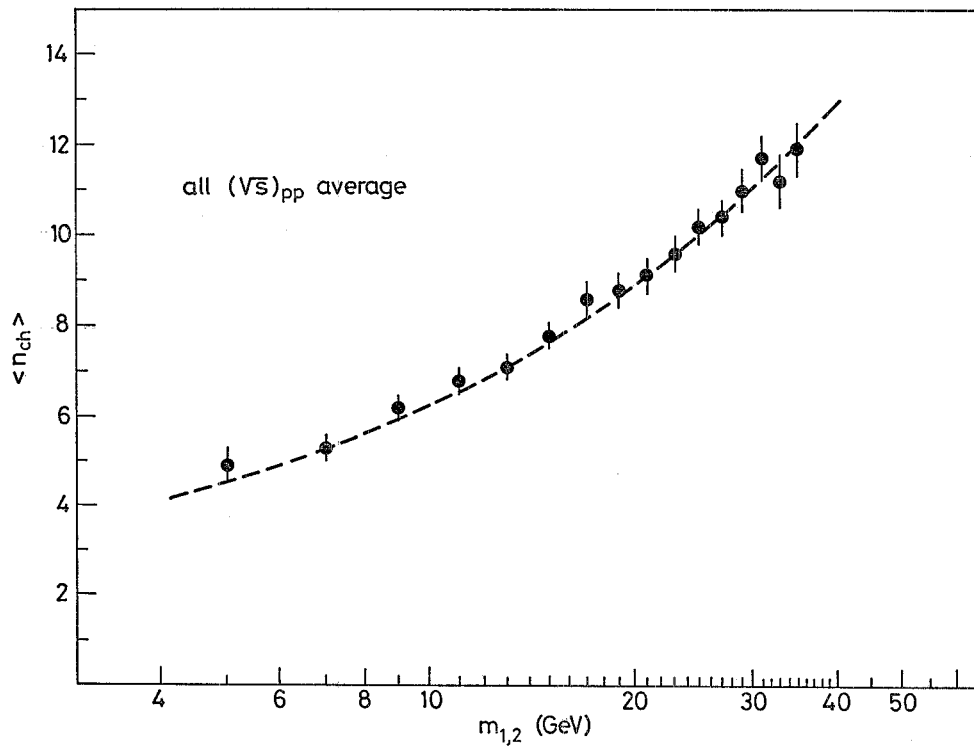
Fig. 5. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $m_{1,2}$ averaged over all $(\sqrt{s})_{pp}$ values. The dashed line is our previously published fit [1].
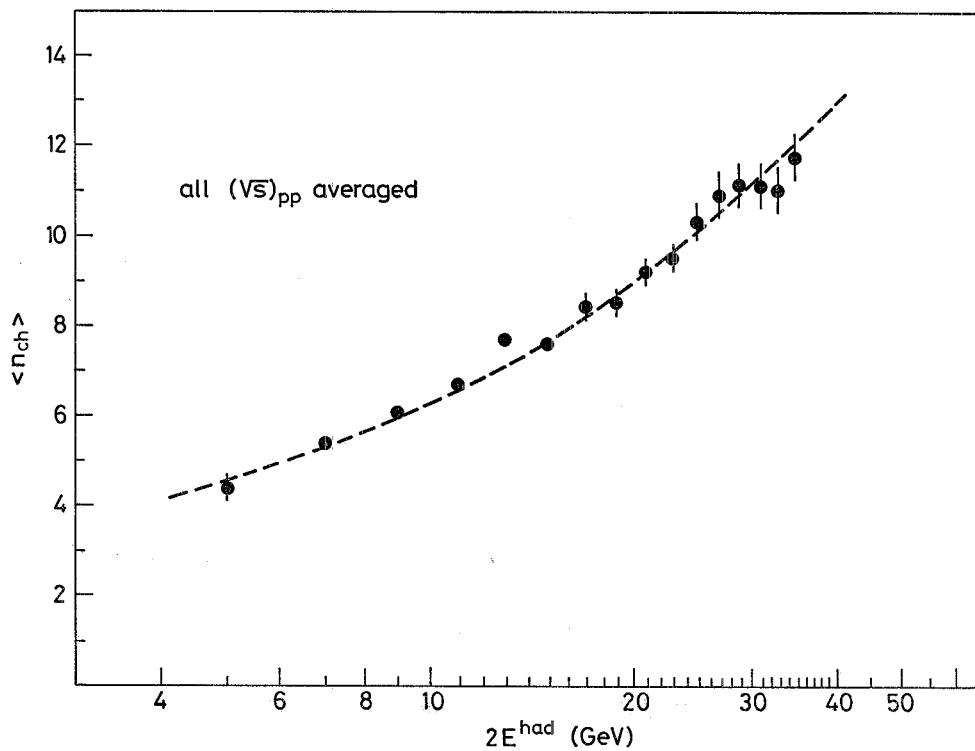

Fig. 6. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $2E^{had}$ averaged over all $(\sqrt{s})_{pp}$ values. The dashed line is our previously published fit [1].
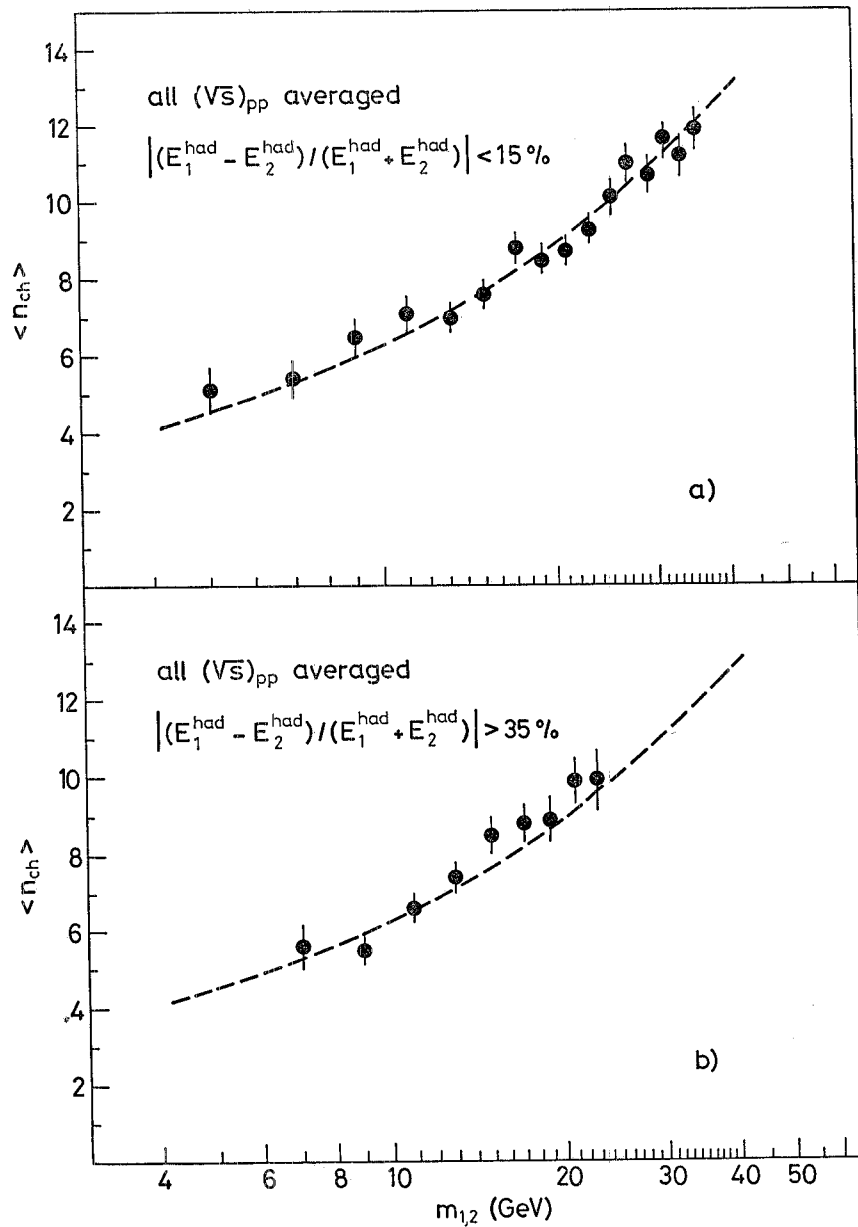
Fig. 7. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $m_{1,2}$ averaged over all $(\sqrt{s})_{pp}$ values, but with the selection a) $|(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| \leqslant 15\%$, b) $|(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| \geqslant 35\%$. The dashed line is our previously published fit [1].
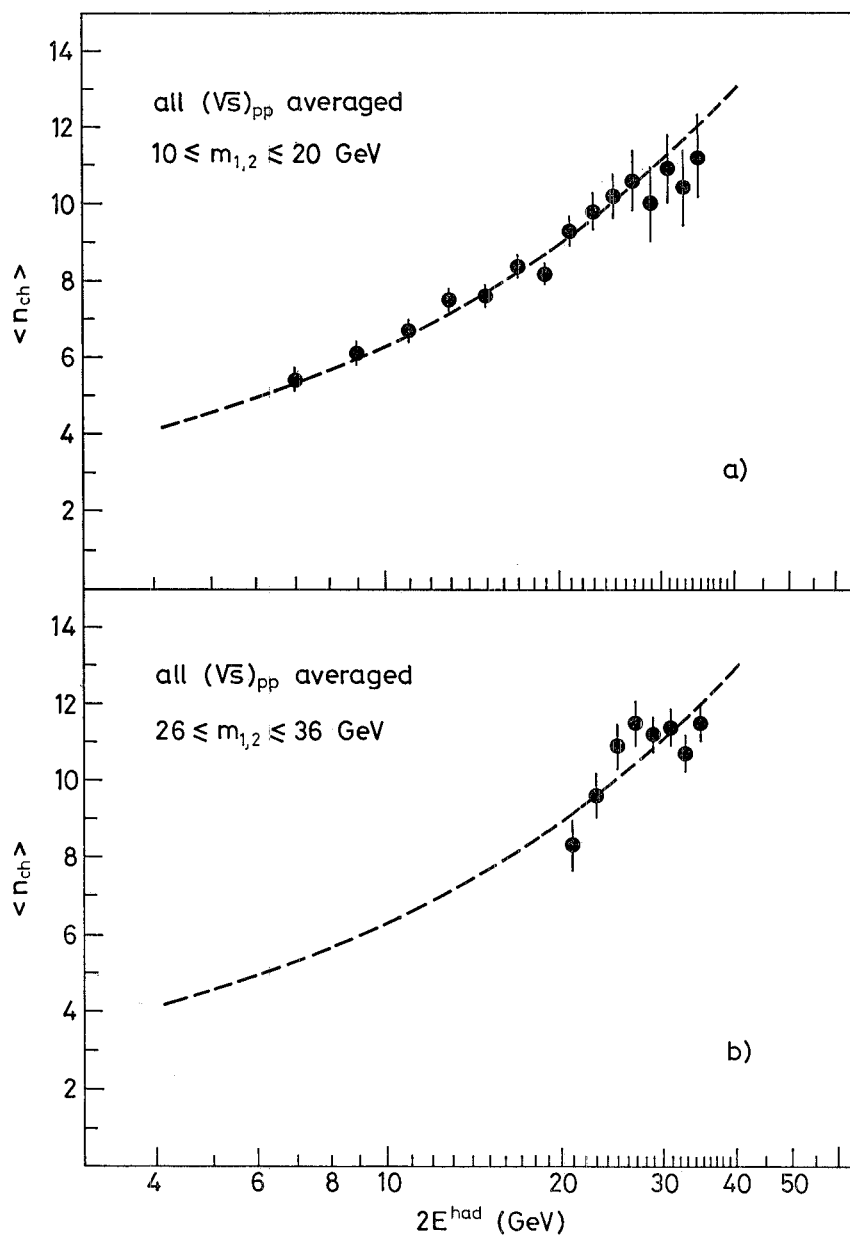
Fig. 8. – Mean charged-particle multiplicity $\langle n_{ch} \rangle$ vs. $2E^{had}$ averaged over all $(\sqrt{s})_p$ values for events with two protons, with the selection a) $10 \leqslant m_{1,2} \leqslant 20$ GeV, b) $26 \leqslant \leqslant m_{1,2} \leqslant 36$ GeV. The dashed line is our previously published fit [1].

For the sake of simplicity, only the values of $\langle n_{ch} \rangle$ averaged over the different $(\sqrt{s})_{pp}$ are reported. No significant differences appear in the comparison of these two samples.

A second test, complementary to the first one, has also been done, *i.e.* the study of the influence, on the values of $\langle n_{ch} \rangle$ *vs.* $2E^{had}$, of the quantity $m_{1,2}$. Two samples of events with $m_{1,2}$ in the intervals $10 \leqslant m_{1,2} \leqslant 20$ GeV and $26 \leqslant \leqslant m_{1,2} \leqslant 36$ GeV were selected; fig. 8a) and b) show $\langle n_{ch} \rangle$, averaged over the three values of $(\sqrt{s})_{pp}$, for these two samples. Again no significant differences appear. This study shows that there is no correlation either in terms of $m_{1,2}$ or in terms of $2E^{had}$.

3. – Conclusion.

The results of the present experiment show that the average charged-particle multiplicities $\langle n_{ch} \rangle$, measured in terms of $m_{1,2}$ (fig. 5) and of $2E^{had}$ (fig. 6), agree with each other and with e⁺e⁻ data. The $(\sqrt{s})_{pp}$ independence is valid in both cases.

● RIASSUNTO

Usando interazioni pp a tre diverse energie nel centro di massa, $(\sqrt{s})_{pp} = 30$, 44, 62 GeV, si mostra che la molteplicità media delle particelle cariche $\langle n_{ch} \rangle$ in funzione della massa invariante del sistema adronico $m_{1,2}$ ha lo stesso andamento che in funzione di $2E^{had}$. Si mostra inoltre che, in entrambi i casi, $\langle n_{ch} \rangle$ è pressoché indipendente da $(\sqrt{s})_{pp}$ e in buon accordo con la molteplicità media delle particelle cariche misurata nel processo di annichilazione (e⁺e⁻).

Подробное исследование зависимости $\langle n_{ch} \rangle$ от E^{had} и $m_{1\,2}$ при различных $(\sqrt{s})_{pp}$ в (pp) взаимодействиях.

Резюме (*). — Используя (pp) взаимодействия при трех различных энергиях в системе центра масс, $(\sqrt{s})_{pp} = 30, 44, 62$ ГэВ, показывается что зависимость средней множественности заряженных частиц $\langle n_{ch} \rangle$ от инвариантной массы адронной системы $m_{1,2}$ имеет такое же поведение, как и зависимость от $2E^{had}$. Более того, показывается, что в обоих случаях $\langle n_{pp} \rangle$ почти не зависит от $(\sqrt{s})_{pp}$ и $\langle n_{ch} \rangle$ хорошо согласуется со средней множественностью заряженных частиц, измеренной при (e⁺e⁻) аннигиляции.