EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/81-146
10 November 1981

# A DETAILED STUDY OF $\langle n_{ch} \rangle$ VERSUS $E^{had}$ AND $m_{1,2}$ AT DIFFERENT $(\sqrt{s})_{pp}$ IN (pp) INTERACTIONS

M. Basile, G. Bonvicini, G. Cara Romeo, L. Cifarelli, A. Contin, M. Curatolo,
G. D'Ali, 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

CERN, Geneva, Switzerland
Istituto di Fisica dell'Università di Bologna, Italy
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, Italy
Istituto Nazionale di Fisica Nucleare, Sezione di Bologna, Italy
Istituto di Fisica dell'Università di Perugia, Italy
Istituto di Fisica dell'Università di Roma, Italy

## ABSTRACT

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 $\langle n_{ch} \rangle$ versus the invariant mass of the hadronic system $m_{1,2}$ has the same behaviour as it has versus $2E^{had}$.

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 $(e^+e^-)$ annihilation.

(Submitted to Nuovo Cimento)

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

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

$$m_{1,2} = \left[\left(E_1^{had} + E_2^{had}\right)^2 - \left(\vec{p}_1^{\,had} + \vec{p}_2^{\,had}\right)\right]^{1/2} , \quad (1)$$

where $E_{1,2}^{had}$ and $\vec{p}_{1,2}^{\,had}$ are the energy and momentum differences between the incident protons and the outgoing leading protons[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 $\langle n_{ch} \rangle$ versus $m_{1,2}$ has the same behaviour as when it is studied in terms of $E^{had}$. In this case it had to scale with $(\sqrt{s})_{pp}$ and it had to be in good agreement with $e^+e^-$ data when $2E_{beam}^{e^+,e^-} = 2E^{had} = m_{1,2}$. Moreover, it is important to study whether $\langle n_{ch} \rangle$ versus $m_{1,2}$ depends on the selection of given values of $E^{had}$, and also whether $\langle n_{ch} \rangle$ versus $E^{had}$ depends on any selection of $m_{1,2}$ values.

## 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 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 $x_F$ ($x_F = 2p_L/\sqrt{s}$, where $p_L$ is the longitudinal proton momentum) in the range

$$0.42 \leq x_F \leq 0.86 \tag{2}$$

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, where 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].

The charged particle multiplicity has been measured 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 $K_S^0 \rightarrow \pi^+\pi^-$ has been subtracted. Other small contributions, such as $\gamma$ 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 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 1 and in Figs. 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 agreement with our previously published[1] best fit to $\langle n_{ch} \rangle$ versus $E^{had}$ (dashed line). These data show that, within the experimental uncertainties, $\langle n_{ch} \rangle$ versus $m_{1,2}$ nearly scales with $(\sqrt{s})_{pp}$. In Table 1 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 Figs. 5 and 6. The agreement with the $e^+e^-$ data, as 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 $\langle n_{ch} \rangle$ versus $m_{1,2}$ and $2E^{had}$.

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

i) events whose $m_{1,2}$ is obtained by combining nearly equal values of $E^{had}$ $\{|(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| \leq 15\%\}$;

ii) events whose $m_{1,2}$ is obtained by combining very different values of $E^{had}$ $\{|(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| \geq 35\%\}$.

The values of $\langle n_{ch} \rangle$ versus $m_{1,2}$ for these two samples are shown in Figs. 7a and 7b. 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 $\langle n_{ch} \rangle$ versus $2E^{had}$, of the quantity $m_{1,2}$. Two samples of events with $m_{1,2}$ in the intervals $10 \leq m_{1,2} \leq 20$ GeV and $26 \leq m_{1,2} \leq 36$ GeV, were selected; Figs. 8a and 8b 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 multiplicity $\langle n_{ch} \rangle$, 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.

REFERENCES

1) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, 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, preprint CERN-EP/81-76 (1981), Nuovo Cimento, in press.

2) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, 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. 99B, 247 (1981).

3) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, Phys. Lett. 92B, 367 (1980).

4) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, Phys. Lett. 95B, 311 (1980).

5) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, Nuovo Cimento 58A, 193 (1980).

6) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, Nuovo Cimento Lett. 29, 491 (1980).

7) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, G. Sartorelli, M. Spinetti, G. Susinno, G. Valenti and A. Zichichi, Nuovo Cimento Lett. 30, 389 (1981).

8) M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, G. Sartorelli, G. Valenti and A. Zichichi, Nuovo Cimento Lett. 31, 273 (1981).

9) 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).

10) P. Capiluppi, G. Giacomelli, A.M. Rossi, G. Vannini and A. Bussière, Nucl. Phys. B70, 1 (1974).

P. Capiluppi, G. Giacomelli, A.M. Rossi, G. Vannini, A. Bertin, A. Bussière and R.J. Ellis, Nucl. Phys. B79, 189 (1974).

Table 1

Mean charged particle multipl city $\langle n_{ch} \rangle$ versus $2E^{had}$ 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%.

| | $\langle n_{ch} \rangle$ versus $2E^{had}$ | | | | |
|---|---|---|---|---|---|
| $2E^{had}$ (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 |

| | $\langle n_{ch} \rangle$ versus $m_{1,2}$ | | | | |
|---|---|---|---|---|---|
| $m_{1,2}$ (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 |

Figure captions

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

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

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

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

Fig. 5 : Mean charged particle multiplicity $\langle n_{ch} \rangle$ versus $m_{1,2}$ averaged over all $(\sqrt{s})_{pp}$ values. The dashed line is our previously published fit[1].

Fig. 6 : Mean charged particle multiplicity $\langle n_{ch} \rangle$ versus $2E^{had}$ averaged over all $(\sqrt{s})_{pp}$ values. The dashed line is our previously published fit[1].

Fig. 7 : Mean charged particle multiplicity $\langle n_{ch} \rangle$ versus $m_{1,2}$ averaged over all $(\sqrt{s})_{pp}$ values, but applying the selection

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

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

The dashed line is our previously published fit[1].

Fig. 8 : Mean charged particle multiplicity $\langle n_{ch} \rangle$ versus $2E^{had}$ averaged over all $(\sqrt{s})_{pp}$ values for events with two protons, having applied the selection:

a) $10 \leq m_{1,2} \leq 20$ GeV;

b) $26 \leq m_{1,2} \leq 36$ GeV.

The dashed line is our previously published fit[1].

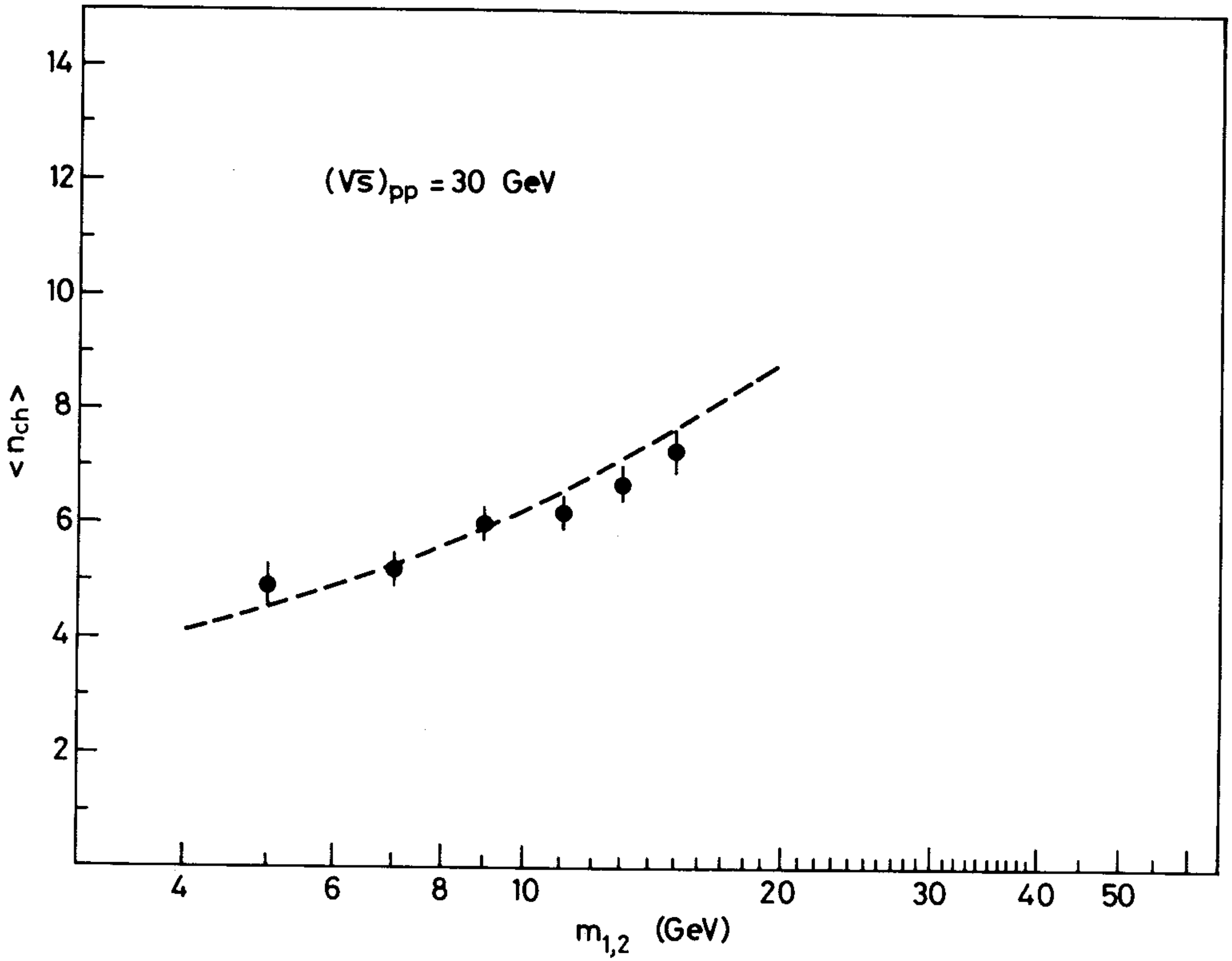



Fig. 1

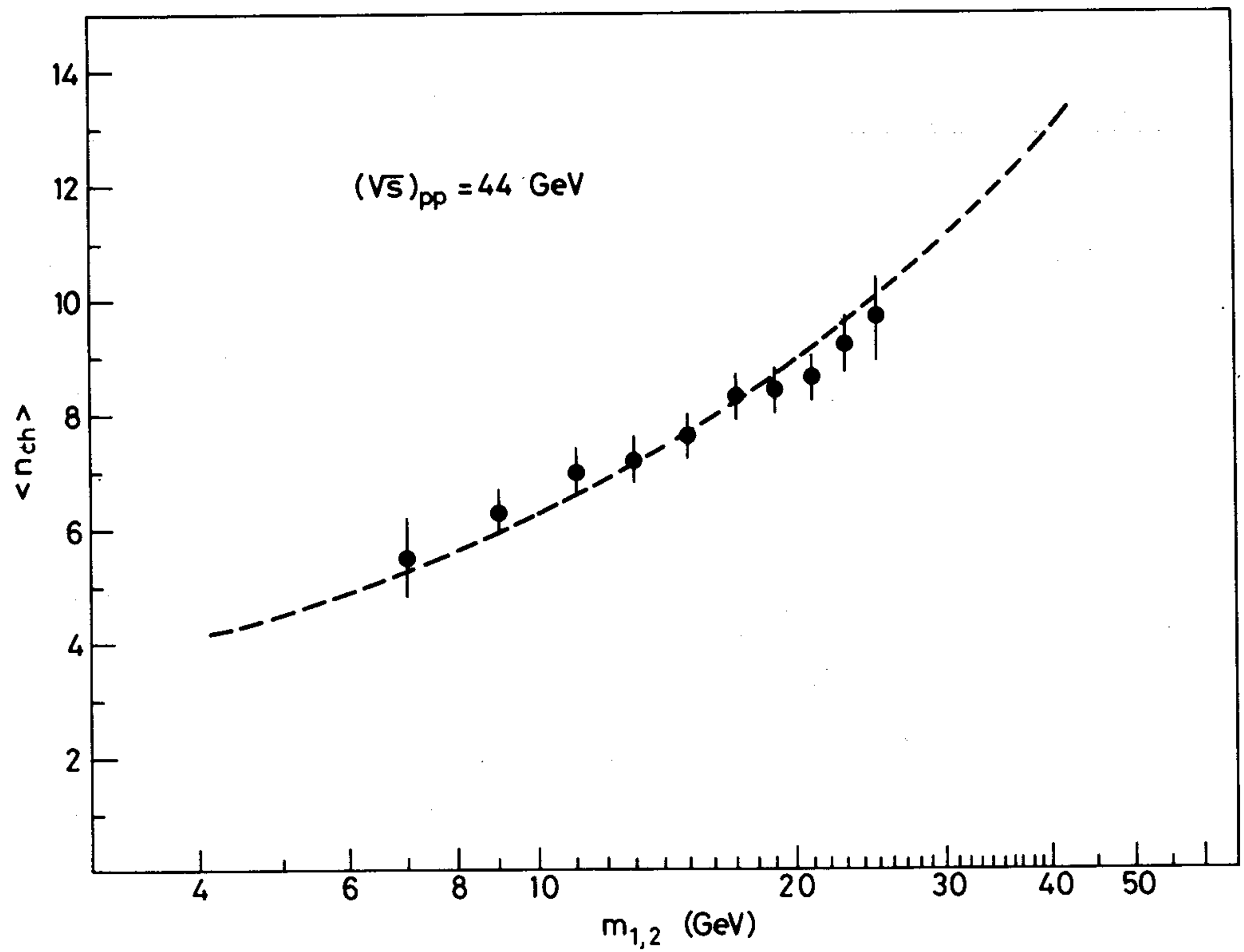



Fig. 2

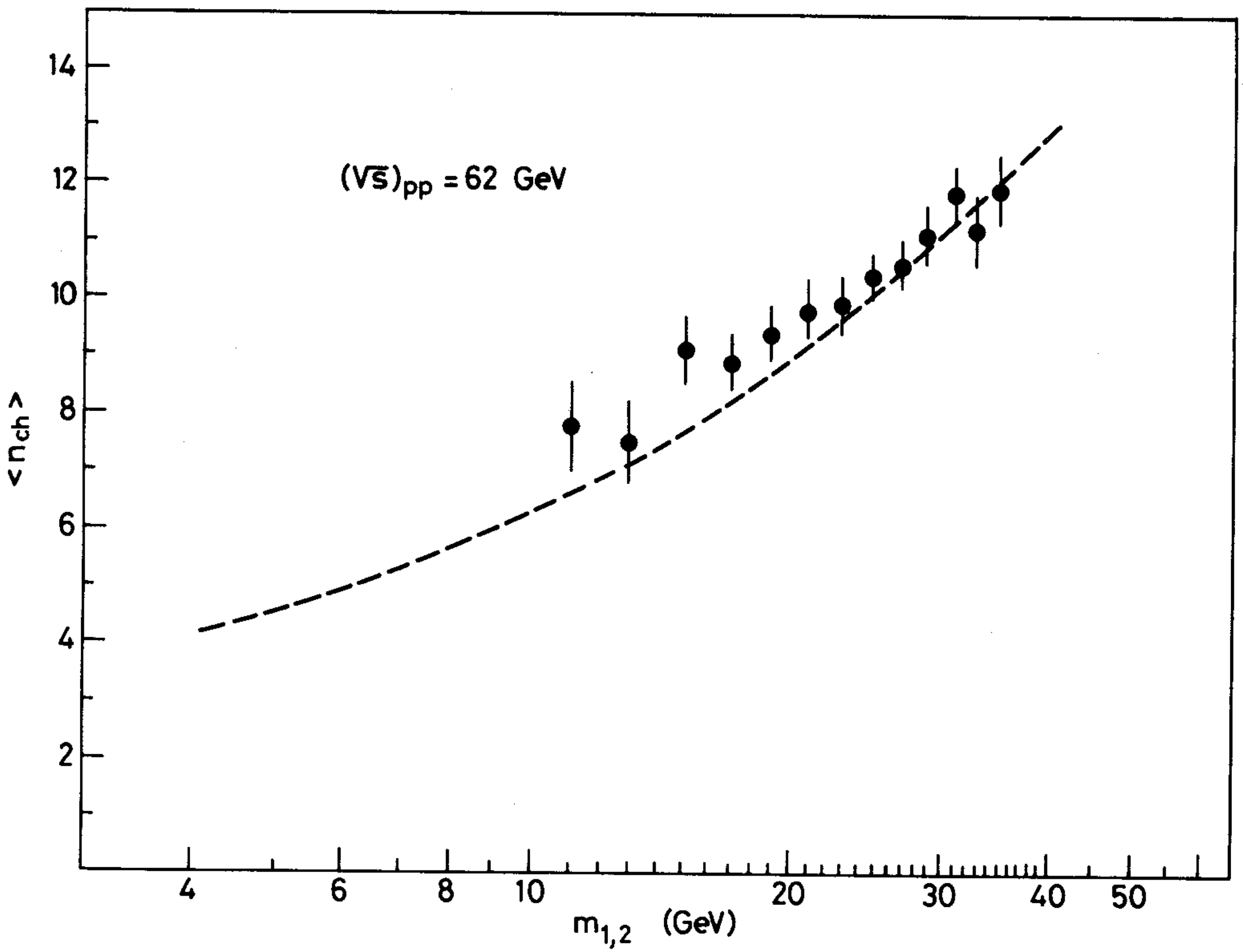
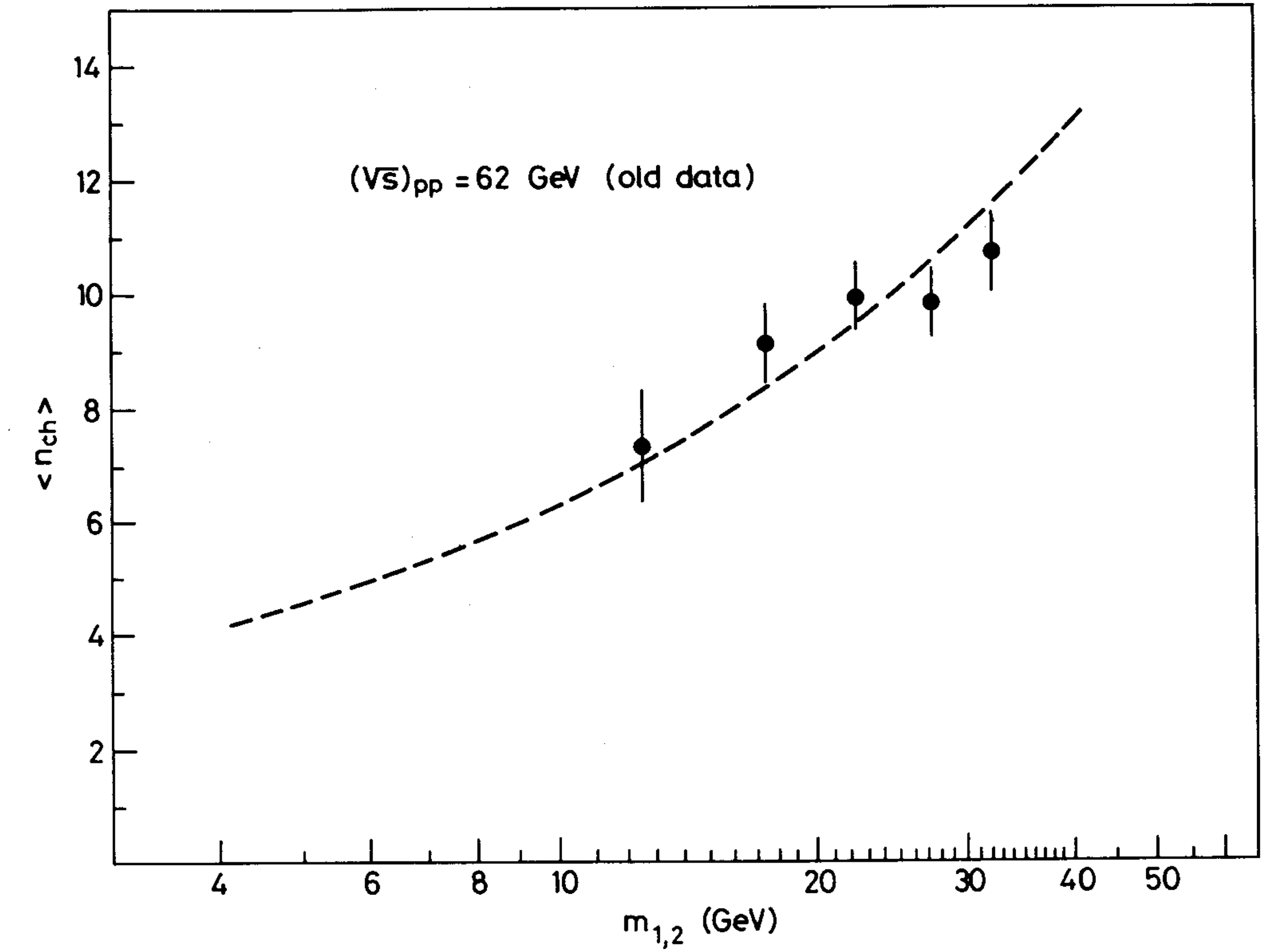



Fig. 3



$(\sqrt{s})_{pp} = 62$ GeV (old data)
$< n_{ch} >$
14
12
10
8
6
4
2
4
6
8
10
20
30
40
50
$m_{1,2}$ (GeV)


Fig. 4

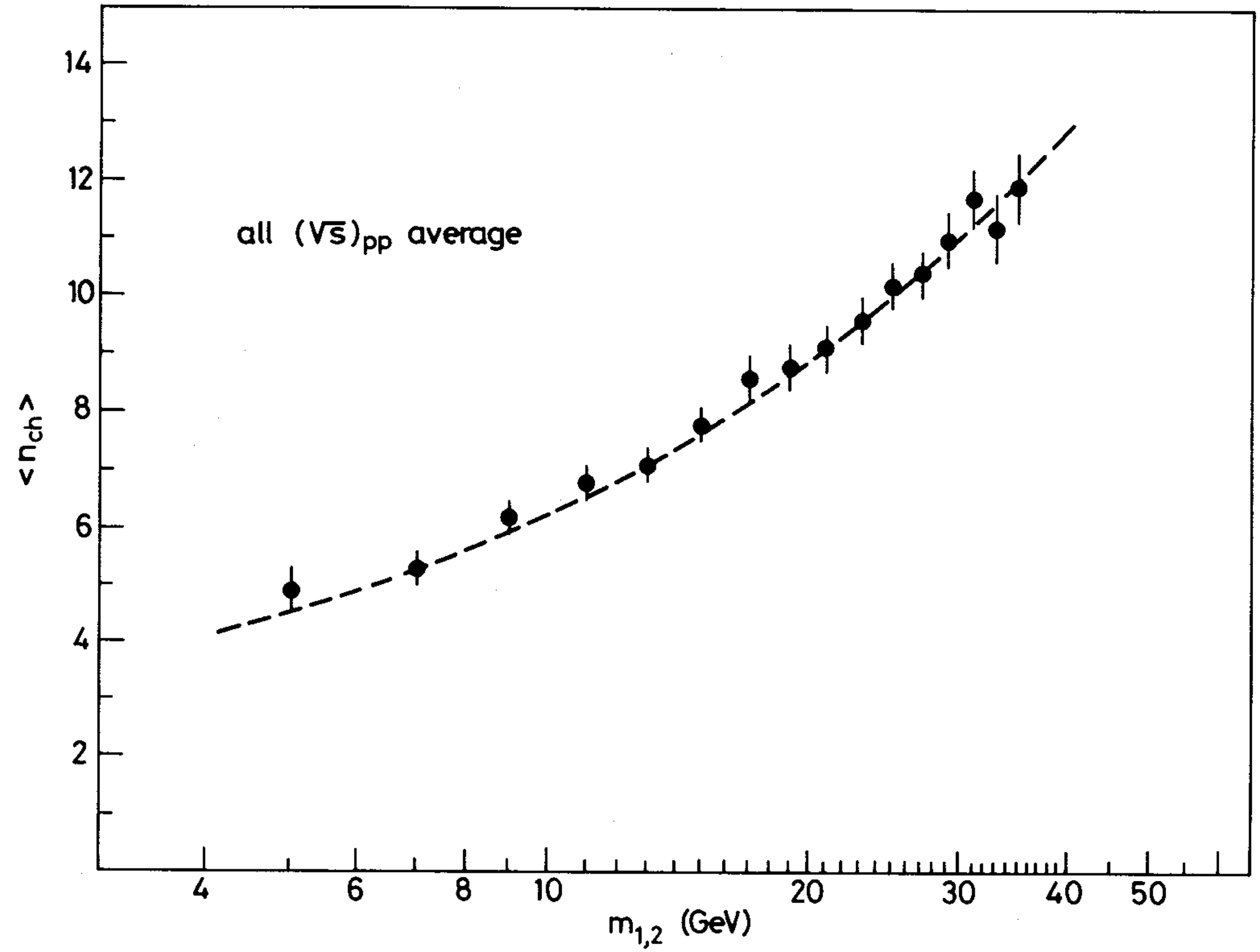
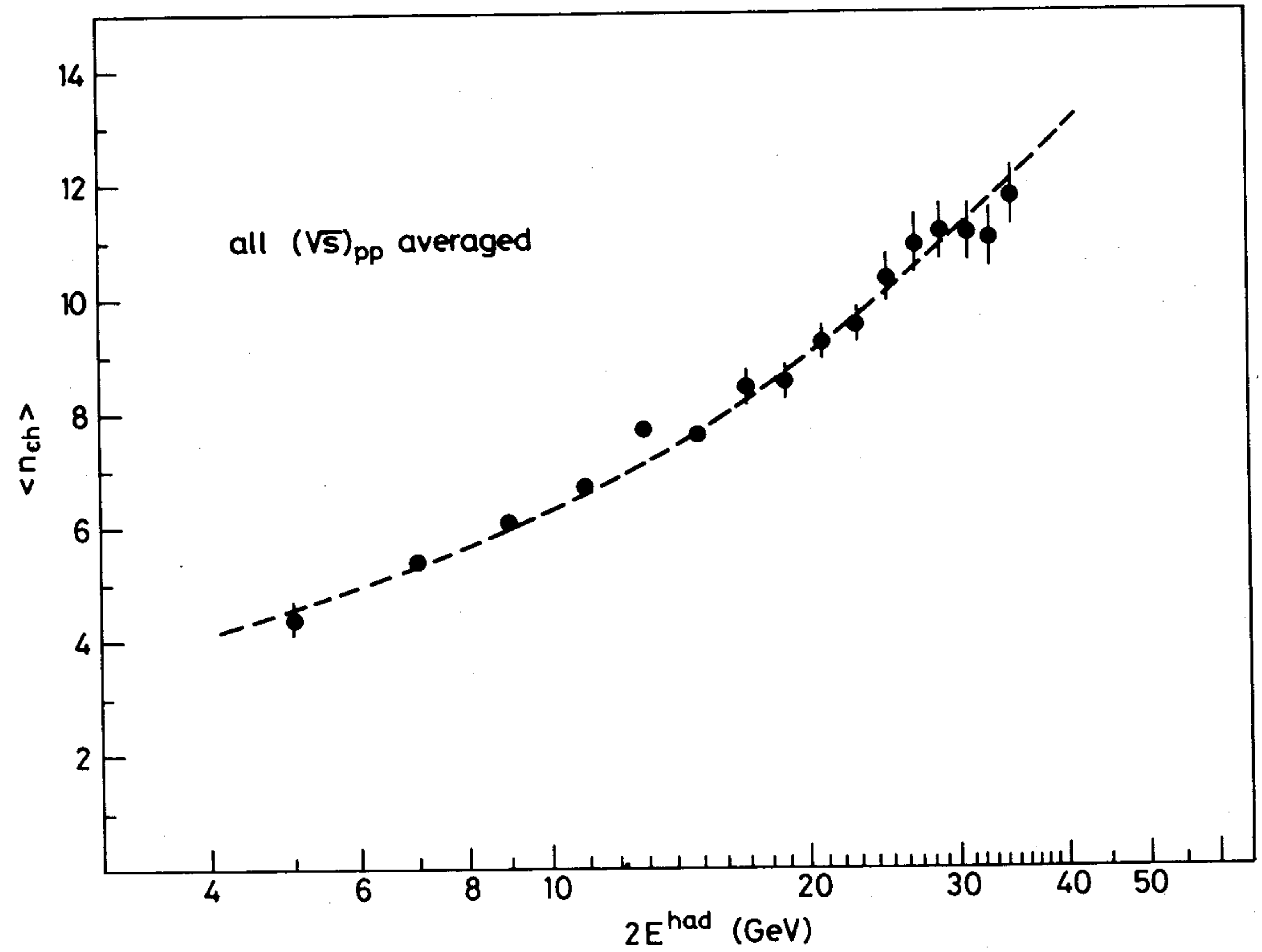



Fig. 5



all $(\sqrt{s})_{pp}$ averaged
14
12
10
8
6
4
2
$<n_{ch}>$
4
6
8
10
20
30
40
50
$2E^{had}$ (GeV)


Fig. 6

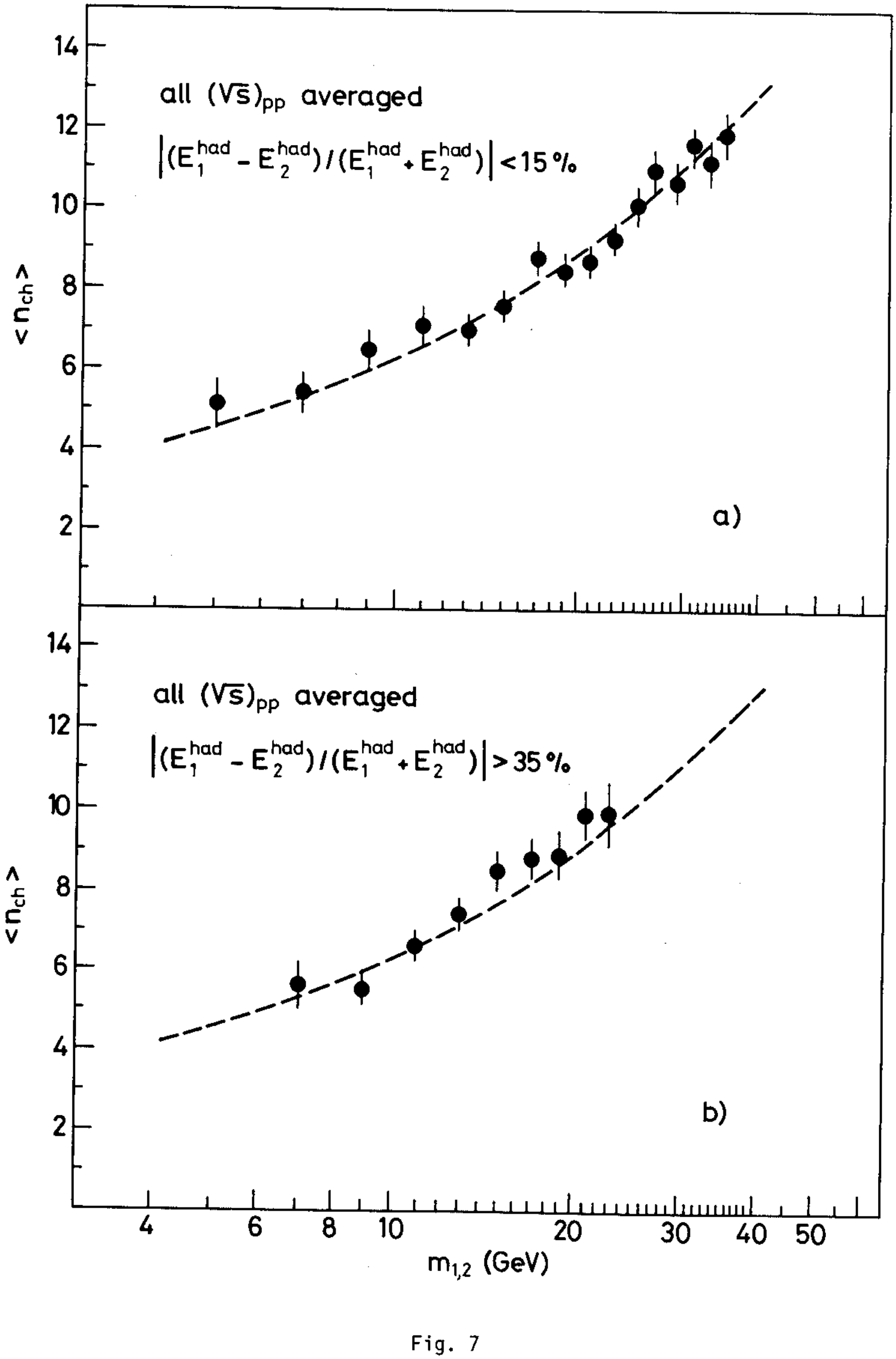
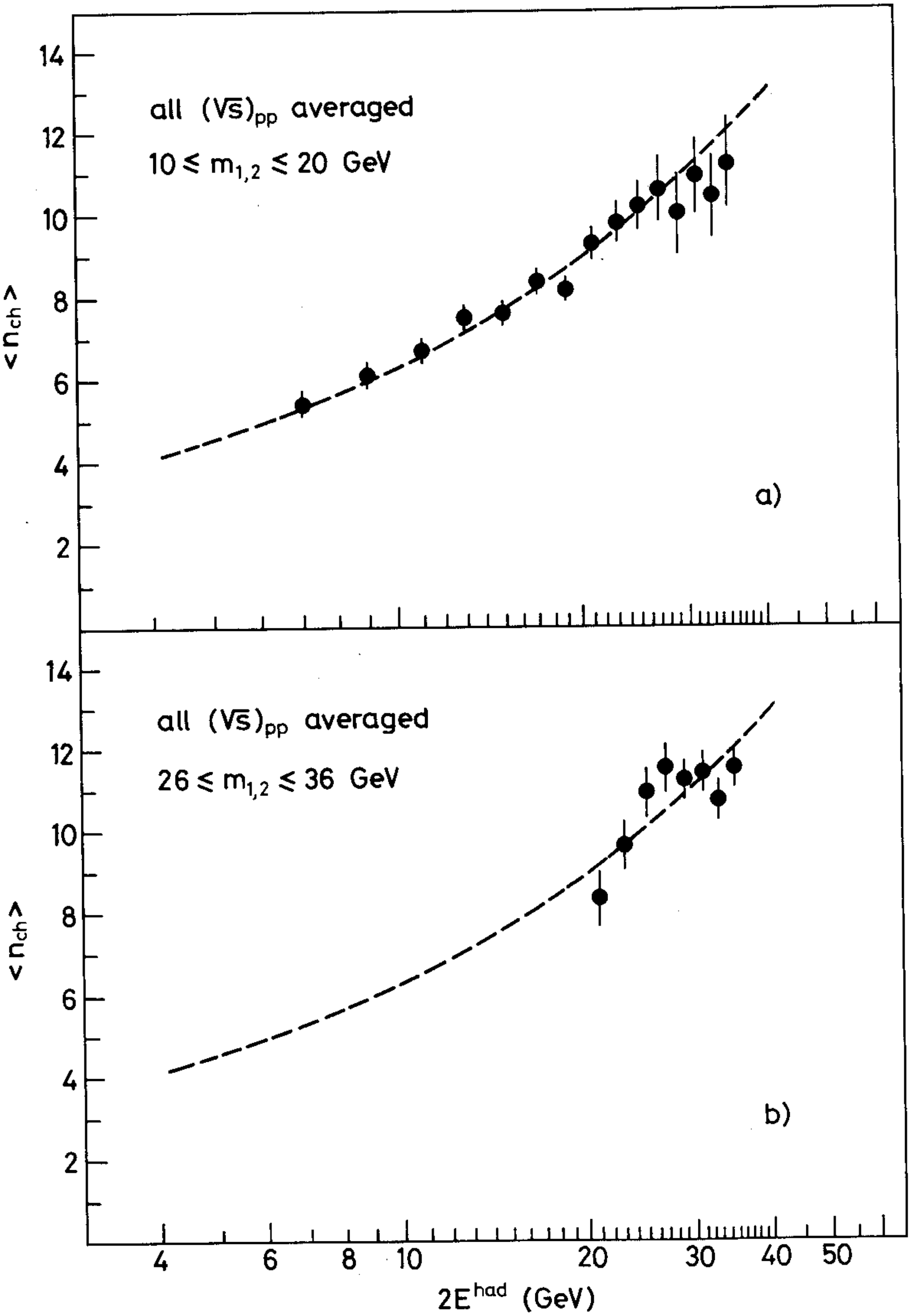

all $(\sqrt{s})_{pp}$ averaged
$|(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| < 15\%$
a)
all $(\sqrt{s})_{pp}$ averaged
$|(E_1^{had} - E_2^{had})/(E_1^{had} + E_2^{had})| > 35\%$
b)
$<n_{ch}>$
$m_{1,2}$ (GeV)
2
4
6
8
10
12
14
20
30
40
50

Fig. 7



all $(\sqrt{s})_{pp}$ averaged
$10 \le m_{1,2} \le 20$ GeV
a)
all $(\sqrt{s})_{pp}$ averaged
$26 \le m_{1,2} \le 36$ GeV
b)
$<n_{ch}>$
$2E^{had}$ (GeV)


Fig. 8