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CHARGED PARTICLE MULTIPLICITIES IN (pp) INTERACTIONS AND COMPARISON WITH (e^+e^-) DATA

M. Basile, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Alì
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 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 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.

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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. The key point of this experiment was to show that the energy available for particle productions 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.

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

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 $\langle n_{ch} \rangle$ measured in (pp) interactions are found to be in excellent agreement with the values of $\langle n_{ch} \rangle$ measured in (e^+e^-) annihilations at the same equivalent energy, i.e.

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

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 $\langle n_{ch} \rangle$.

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.

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 26,491, of which 4582 were at E_{inc} = 15 GeV, 11,689 at E_{inc} = 22 GeV and 10,220 at E_{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 $\sim$ 20,000 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_{inc} = 31 GeV (i.e. $\sqrt{s}$ = 62 GeV), taken with two different "trigger" conditions, was made in order to be sure that the trigger used to enrich the events with a "leading" proton produced the same results as the "minimum bias" trigger. In fact, our first evidence that multiparticle production processes in (pp) interactions was showing remarkable similarities with the (e^+e^-) annihilations, was based on the "minimum bias" trigger events[1]. In this 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 did not introduce any bias.

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

$$E_{inc} = 15 \text{ GeV}$$
$$E_{inc} = 22 \text{ GeV}$$
$$E_{inc} = 31 \text{ GeV}.$$

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 $x_F = 2p_L/\sqrt{s}$,

$$0.35 \le x_F \le 0.86 \ ,$$

needed to identify the "leading" proton, as explained in our previous papers[1-7].

The charged multiplicity has been measured 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 $\lesssim$ 5% amongst the four sets of data, and an over-all systematic uncertainty $\lesssim$ 8%.

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 1 and Fig. 2 show the results at these energies, including the "old data". An inspection of these data show that equal values of $2E_{had}$ obtained from different $\sqrt{s}$, produce, within the experimental limits of uncertainty, the same values of $\langle n_{ch} \rangle$.

This equality answers the main problem of our present investigation.

The data, averaged for each value of $2E_{had}$, are presented in Fig. 3 together with (e^+e^-) data from ADONE, SPEAR, and PETRA[9-11]. A contamination from the $K^0_S \to \pi^+\pi^-$ 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. 3 between (pp) and (e^+e^-) data is very satisfactory. In this figure the "standard" $\langle n_{ch} \rangle$ versus $\sqrt{s}$ in (pp) interactions is also reported for reference.

The agreement between (pp) and (e^+e^-) data can be expressed in a quantitative way with the best fits. The continuous line in Fig. 3 is the best fit to our 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 using the following analytic form[15-17]:

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

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*) Invariant phase-space Monte Carlo with limited p_T.

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

In Table 2 the values of $\langle n_{ch} \rangle$, as measured in our experiment with the three values of $\sqrt{s}$, are reported. These data are in excellent agreement with well-known results[13,14] on (pp) interactions and show that, if we analyse $\langle n_{ch} \rangle$ 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. 3. This is an important self-consistency check.

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} available for multiparticle production is determined. The average charged particle multiplicity $\langle n_{ch} \rangle$ scales, as expected, with the total c.m. (pp) energy. In fact, different $(\sqrt{s})_{pp}$ 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 $(\sqrt{s})_{pp}$, i.e. (30, 44, 62) GeV.

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Table 1

Mean charged multiplicity versus $2E_{had}$ 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%.

$2E_{had}$ (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

Table 2

Total charged multiplicities $\langle n_{ch} \rangle$ for the minimum bias samples versus $\sqrt{s}$ of the ISR. The quoted errors include systematic and statistical ones.

$\sqrt{s}$ (GeV)	$\langle n_{ch} \rangle$
30.0	9.4 ± 0.8
44.0	11.1 ± 1.0
62.0	12.4 ± 1.1

Figure captions

Fig. 1 : ($2E_{had}$) range corresponding to each incident energy E_{inc}. Notice the overlap region where different E_{inc} produce the same ($2E_{had}$) values. The range of ($2E_{had}$) at each E_{inc} is determined by the x_F values chosen to identify the "leading" proton.

Fig. 2 : Mean charged multiplicity $\langle n_{ch} \rangle$ versus ($2E_{had}$) for different $\sqrt{s}$ of the ISR. The measured multiplicity has been multiplied by 2 in order to compare it with (e^+e^-) data. The quoted errors are statistical only. The systematic effects are less than 8%.

Fig. 3 : Mean charged multiplicity averaged over different $\sqrt{s}$ versus ($2E_{had}$) compared with (e^+e^-) data. The contribution of $K_S^0 \to \pi^+\pi^-$ 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 according to the formula $\langle n_{ch} \rangle = a + b \exp\left[c\sqrt{\ln (s/\Lambda^2)}\right]$ (Refs. 15-17). The dotted line is the best fit using PLUTO data (Ref. 9). The dashed-dotted line is the (pp) total charged multiplicity (Refs. 13 and 14). For this curve, the abscissa is $(\sqrt{s})_{pp}$. The triangular points in this curve are our data.

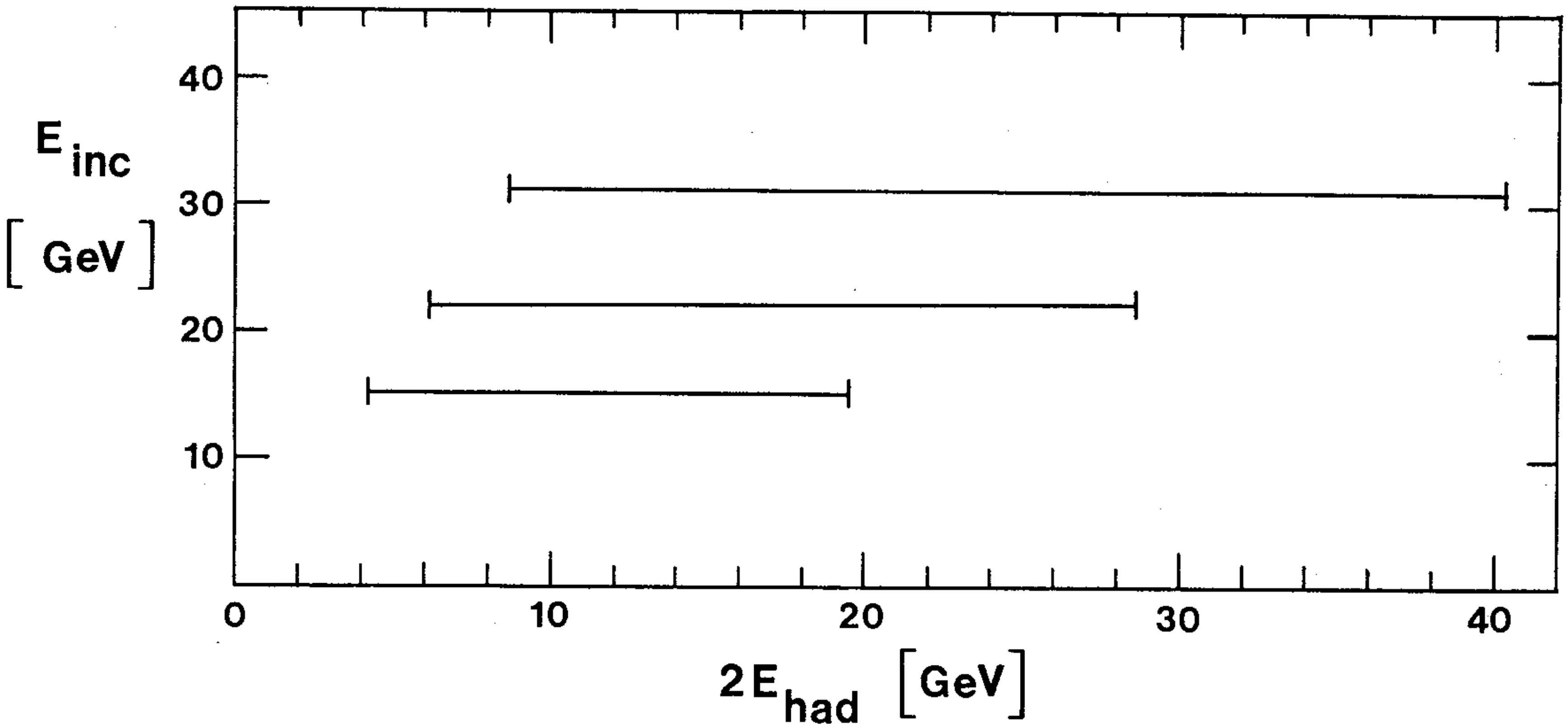
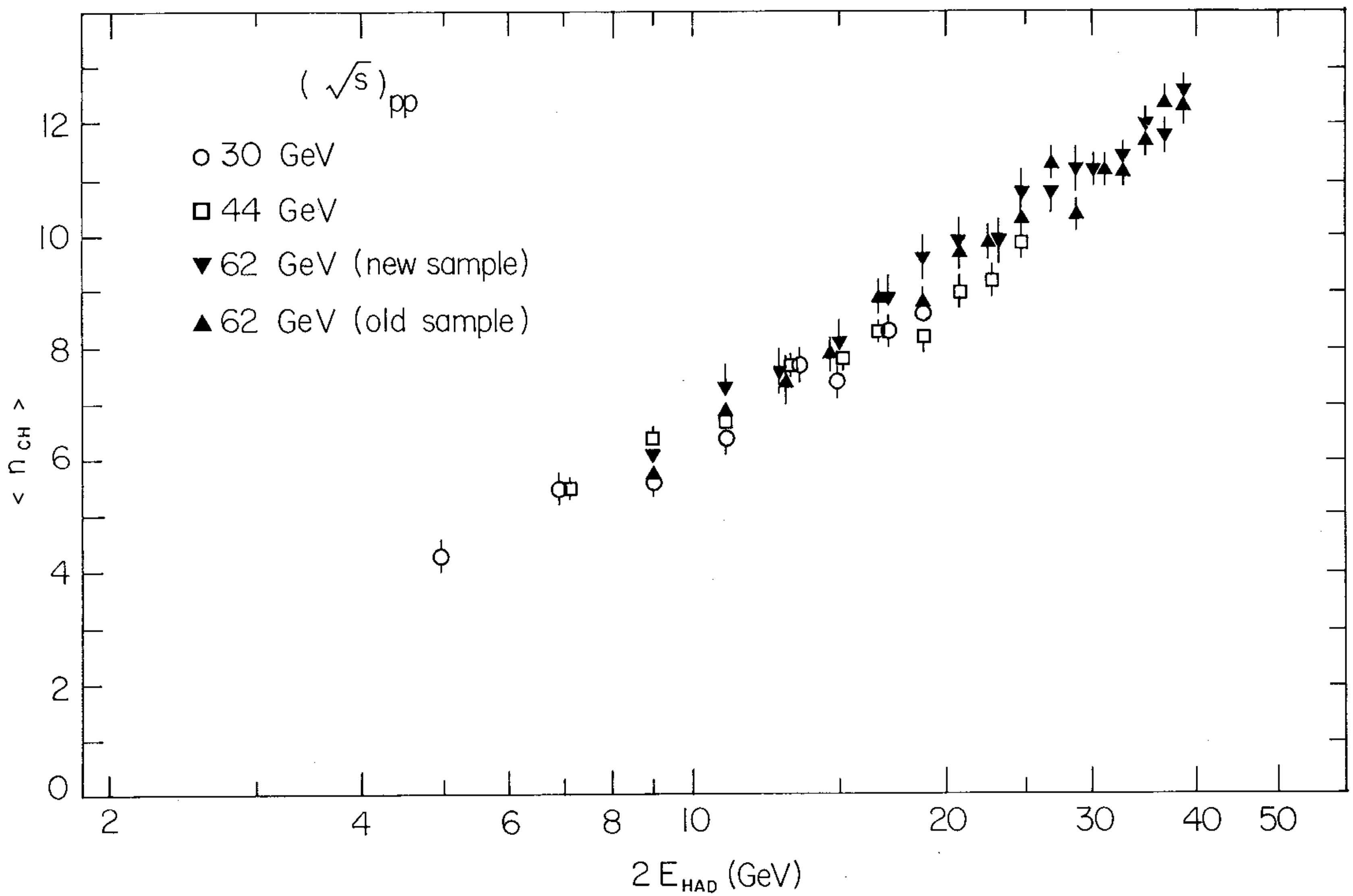
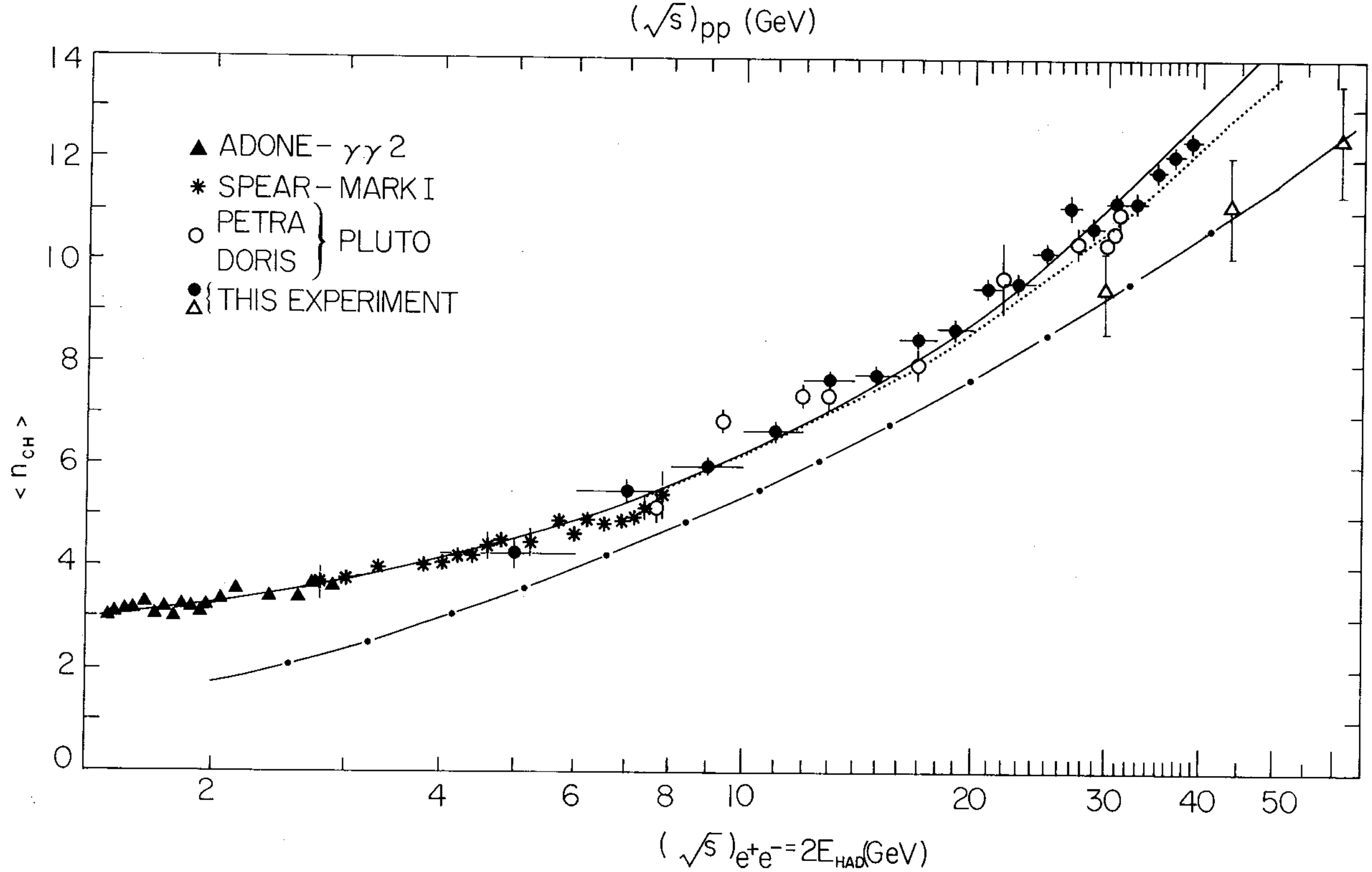


Fig. 1



$(\sqrt{s})_{pp}$
30 GeV
44 GeV
62 GeV (new sample)
62 GeV (old sample)
$< n_{CH} >$
0
2
4
6
8
10
12
2
4
6
8
10
20
30
40
50
$2E_{HAD}$ (GeV)

Fig. 2



(√s)pp (GeV)
▲ ADONE - γγ 2
✱ SPEAR - MARK I
○ PETRA
DORIS
PLUTO
● △ THIS EXPERIMENT
< n_CH >
14
12
10
8
6
4
2
0
2
4
6
8
10
20
30
40
50
(√s)e+e- = 2E_HAD (GeV)

Fig. 3