PUB-81-109-E
E-0299
E-0565
E-0570

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~~Submitted to~~
Physics Letters B
~~February 22, 1981~~

TECHNION-PH-80-58

22 February, 1981

THE EFFECTIVE-ENERGY DEPENDENCE OF THE CHARGED PARTICLES MULTIPLICITY IN $p/\pi^+/K^+$ INTERACTIONS ON PROTONS AT 147 GeV/c

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ABSTRACT

The energy dependence of the average of the charged multiplicity and its dispersion in $\pi^+/K^+/p$ interactions on protons at 147 GeV/c is found to be the same as in e^+e^- annihilations if an "effective energy" variable is used instead of the total energy. The effective energy $\sqrt{S_{eff}}$ is defined as the invariant mass of all secondaries left after the two leading particles have been removed. Fitting the expression a $S_{eff}^{\ b}$ to the average charge multiplicity $<n_{ch}>$, we find the power b to be in good agreement with the value of 0.25 predicted by Fermi's statistical model and by Landau's hydrodynamical model.

It has long been recognized[1] that the energy dependence of the multiplicity of particles produced in high energy interactions carries information on the interaction mechanism. Large amounts of data have been collected and several models proposed to describe the experimental results; all are summarized in reviews such as those by J. Whitmore and A. Wroblewski[2].

It is however possible to extend such studies with the advent of new e^+e^- results[3] and the observation by Basile et al.[4] that the behaviour of the e^+e^- and pp systems is essentially the same using for p-p the energy left after subtraction of the leading particles (which we further designate "effective energy") while the total energy is used for e^+e^-. (This method had already been suggested by F. Cooper et al.[5].)

In this letter we present results from an experiment with the FERMILAB 30" Hybrid Bubble Chamber Spectrometer exposed to a composite (46% p, 47% π^+, 7%K^+) beam at 147 GeV/c. The apparatus and data reduction techniques have already been described elsewhere[6]. We study the charged multiplicity distributions with the three kinds of projectiles in terms of an "effective energy variable" $\sqrt{S_{eff}}$, where S_{eff} is defined as the square of the four-momentum left after subtracting the positive secondaries for which the Feynman x-variable has the largest magnitude in each of the forward and the backward hemispheres:

$$S_{eff} = (P_{inc} + P_{target} - P_{ff} - P_{bf})^2$$

where P_{inc}, P_{target} are four vectors momentum-energy of initial particles and P_{ff}, P_{bf} are the same for forward/backward positively charged outgoing particles with largest x. We include in our sample only such events, which satisfy both of the following conditions: $x_{ff} > .3$ and $x_{bf} < -.3$. We checked that the present results do not depend on that cut which only affects the available range of effective energy.

To study the multiplicity, Basile et al,[4] counted the charged particles in one hemisphere only and associated the observed number with one half of the available "hadronic energy". This folding technique may introduce detection biases when for example one of the leading particles (or more) is neutral. Our criterion automatically discards such events, making our sample free from such possible detection biases.

In figure 1a we display the dependence of the average number of charged particles which are left after subtraction (thereafter called the charged multiplicity, n_{ch}) versus the observed value of $\sqrt{S_{eff}}$. S_{eff} was calculated event by event, and the events grouped into a reasonable number of bins such as to keep significant statistics in each effective energy interval (intervals and corresponding number of events are part of Table 1). We first note that the region of the effective energy covered by the present experiment lies just below that available in ref. [4] (pp at $\sqrt{s} = 62$ GeV), with very good compatibility of the data where they meet. It is further obvious from Fig. 1a that a linear dependence on $\ln S_{eff}$ cannot describe the data in the whole region of S_{eff} available in our experiment and in that of ref. [4].

We tried to fit the expression $a + b \ln S_{eff} + c(\ln S_{eff})^2$ to our hadronic [illegible] and found the value of b to be compatible with zero for all the projectiles in our experiment. Therefore we then tried to fit the expression $a + c(\ln S_{eff})^2$ to our data and found the following best fits:

$$\langle n_{ch}\rangle_{pp} = (2.12 \pm .046) + (.179 \pm .004)(\ln S_{eff})^2$$

$$\langle n_{ch}\rangle_{\pi^+p} = (2.17 \pm .055) + (.175 \pm .004)(\ln S_{eff})^2$$

$$\langle n_{ch}\rangle_{K^+p} = (2.28 \pm .15) + (.160 \pm .017)(\ln S_{eff})^2$$

with $\chi^2/N_{df} = 1.05$, 3.2, and 1.05, respectively.

For our pp data combined with those of Basile et al.[4] we found

$$\langle n_{ch}\rangle_{pp} = (2.10 \pm .04) + (.182 \pm .004) \quad (\ln S_{eff})^2 \quad (\chi^2/N_{df} = 1.9).$$

The energy dependent term is in remarkable agreement with the result observed in e^+e^- interactions at PLUTO[3]:

$$\langle n_{ch}\rangle_{e^+e^-} = (2.96 \pm 0.03) + (0.18 \pm 0.01)(\ln S)^2 \qquad (\chi^2/N_{df} = 1.5)$$

as well as for all available e^+e^- data[3] for which we found

$$\langle n_{ch}\rangle_{e^+e^-} = (2.76 \pm .08) + (.178 \pm .003) \ (\ln S)^2 \qquad (\chi^2/N_{df} = 2.9).$$

In Fig. 1b, we display data from e^+e^- interactions[3].

The lower solid curve in figures 1a and 1b is the best fit to the hadronic data points, while the upper solid curve corresponds to all e^+e^- data.

The difference between e^+e^- and hadronic data may eventually be attributed to the inclusion of K_s^o decays in e^+e^- samples, which would require a correction estimated to about 0.7 charged units[7].

We have also fitted the expression aS^b to all available e^+e^- data and found:

$$\langle n_{ch}\rangle_{e^+e^-} = (2.20 \pm 0.06)S^{(0.23 \pm 0.01)} \qquad (\chi^2/N_{df} = 3).$$

Fitting the same expression to our data we find:

$$\langle n_{ch}\rangle_{pp} = (1.76 \pm .07)S_{eff}^{(0.26 \pm 0.003)}$$

$$\langle n_{ch}\rangle_{\pi^+p} = (1.76 \pm .07)S_{eff}^{(.26 \pm .003)}$$

$$\langle n_{ch}\rangle_{K^+p} = (1.77 \pm .16)S_{eff}^{(.25 \pm .02)}$$

with $\chi^2/N_{df} = 1.69$, 3.3 and 1.1 respectively, while for combined pp data

$$\langle n_{ch}\rangle_{pp} = (1.74 \pm .04)\ S_{eff}^{(.26 \pm .005)} \qquad (\chi^2/N_{df} = 1.8).$$

We note that the power of S_{eff} which we obtain is consistent with the value of 0.25 predicted by the statistical model of Fermi[1] and by the hydrodynamical model of Landau[8]. The same is true for the power obtained for e^+e^- data.

The lower and upper dashed curves in figure 1a and 1b show the best fit of the expression aS_{eff}^{b} to our hadronic data and to e^+e^- data respectively. They reflect the very good agreement of the values found for the power of S.

In Fig. 2, we display the dispersion D defined as usual by:

$$D^2 = <n^2> - <n>^2$$

as a function of S_{eff}. We have fitted the expression $a+b \ln S_{eff}$ to our data and found the following best fits:

$$D_{pp} = (.21 \pm .037) + (.535 \pm .015) \ln S_{eff}$$

$$D_{\pi^+p} = (.36 \pm .050) + (.479 \pm .016) \ln S_{eff}$$

$$D_{K^+p} = (.34 \pm .21) + (.478 \pm .065) \ln S_{eff}$$

with χ^2/N_{df} = 1.2, 3.2 and 0.95 respectively.

The solid and dashed straight lines in Fig. 2 display the fit for our pp and π^+p data, respectively. We also show in Fig. 2 the e^+e^- PLUTO data and note the good agreement with our results.

We finally remark that we observe quite similar results for $<n_{ch}>$ for pp, π^+p and K^+p interactions, where data were obtained with the same apparatus, during the same exposure, with identically the same technique. For D we observe an indication of a difference between pp and π^+p.

To summarize, using the "effective-energy" obtained after subtracting the two leading particles we observe that:

1. pp, π^+p and K^+p interactions produce the same average charged multiplicity distributions $\langle n_{ch} \rangle$. There is possible indication of a difference for D between pp and π^+p.

2. hadronic data at high energies (pp from ISR[4] and this experiment) vary smoothly with effective energy and with the same dependence as e^+e^- data[3]. One can however not ignore a global shift of the curves obtained for hadronic and e^+e^- interactions.

3. the average charged multiplicity $\langle n_{ch} \rangle$ for hadronic interactions needs a $(\ln S_{eff})^2$ term in the energy range S_{eff} between 1 and 2000 GeV^2.

4. the dispersion D for hadronic interactions is well described by the expression $a + b \ln S_{eff}$ in the energy range S_{eff} between 1 and 150 GeV^2.

It is tempting to interpret those findings in terms of quark interactions. Indeed e^+e^- results have been described in terms of quark-antiquark production. The similarity of hadronic results with e^+e^- annihilation might suggest the contribution of the same mechanism.

However, as discussed by J.F. Gunion[7], this "seemingly simple result requires a rather sophisicated explanation". It is not as simple as it may seem to find which if any diagram is responsible for those observations.

This work was supported in part by the Israeli Academy of Sciences (Commission for Basic Research), the U.S. Department of Energy, the National Science Foundation, the U.S.-Israel Binational Science Foundation and the Dutch F.O.M. We gratefully acknowledge FERMILAB for making the experiment possible and the efforts of the 30-inch bubble-chamber crew and the scanning and measuring personnel at the participating institutions.

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FIGURE CAPTIONS

Fig. 1a Effective energy dependence of the average charged multiplicity from hadronic interactions. The lower solid curve represents a fit of the expression $a+b\,(\ln S_{eff})^2$ to the data, while the lower dashed curve represents a fit of the expression $aS_{eff}^{\ b}$. The upper curves are taken from Fig. 1b.

Fig. 1b Energy dependence of the average charged multiplicity from e^+e^- interactions. The upper solid curve represents a fit of the expression $a+b(\ln S_{eff})^2$ to the data, while the upper dashed curve represents a fit of the expression $aS_{eff}^{\ b}$. The lower curves are taken from Fig. 1a.

Fig. 2 Effective energy dependence of the dispersion from this experiment and from e^+e^- PLUTO data. The solid and dashed lines represent the fits of the expression $a+b\ln S_{eff}$ to pp and π^+p.

TABLE 1

Average Charged Multiplicity and Dispersion for pp, π^+p and K^+p Interactions at 147 GeV/c

EFF ENERGY (GeV) (*)	NUMBER OF EVENTS	$<n_{ch}>$	D
pp			
0.42-2.30	200	2.23 ± .05	0.64 ± .03
2.30-3.61	200	3.07 ± .10	1.41 ± .07
3.61-4.57	200	3.54 ± .11	1.65 ± .08
4.57-5.62	200	3.97 ± .14	1.95 ± .09
5.62-6.45	200	4.51 ± .15	2.05 ± .10
6.45-7.38	200	4.63 ± .15	2.16 ± .10
7.38-8.16	200	5.46 ± .17	2.50 ± .12
8.16-8.75	200	5.29 ± .16	2.24 ± .11
8.75-9.45	200	5.35 ± .19	2.71 ± .14
9.45-10.18	200	5.66 ± .20	2.88 ± .14
10.18-10.97	200	6.32 ± .20	2.83 ± .14
10.97-11.87	200	6.66 ± .21	2.95 ± .15
π^+p			
0.33-2.44	200	2.30 ± .06	0.82 ± .04
2.44-3.78	200	3.35 ± .11	1.62 ± .08
3.78-5.06	200	3.71 ± .11	1.59 ± .08
5.06-6.11	200	3.95 ± .13	1.84 ± .09
6.11-6.88	200	4.62 ± .13	1.96 ± .10
6.88-7.70	200	4.98 ± .16	2.24 ± .11
7.70-8.50	200	5.28 ± .18	2.63 ± .13
8.50-9.13	200	5.41 ± .19	2.68 ± .13
9.13-9.82	200	5.90 ± .19	2.69 ± .13
9.82-10.41	200	5.84 ± .19	2.70 ± .13
10.41-11.15	200	6.59 ± .20	2.86 ± .14
11.15-11.88	200	5.79 ± .18	2.54 ± .12
11.88-12.92	200	6.99 ± .19	2.82 ± .14

TABLE I

(Cont'd)

EFF ENERGY (GeV) (*)	NUMBER OF EVENTS	$\langle n_{ch} \rangle$	D
K^+p			
0.60-4.20	50	2.80 ± .16	1.20 ± .12
4.20-6.24	50	3.84 ± .25	1.78 ± .18
6.24-7.74	50	4.84 ± .30	2.15 ± .21
7.74-9.35	50	5.64 ± .39	2.82 ± .28
9.35-10.38	50	5.20 ± .33	2.33 ± .23
10.38-11.42	50	6.20 ± .38	2.75 ± .27

(*) Intervals were selected so as to yield the same number of events in each interval.

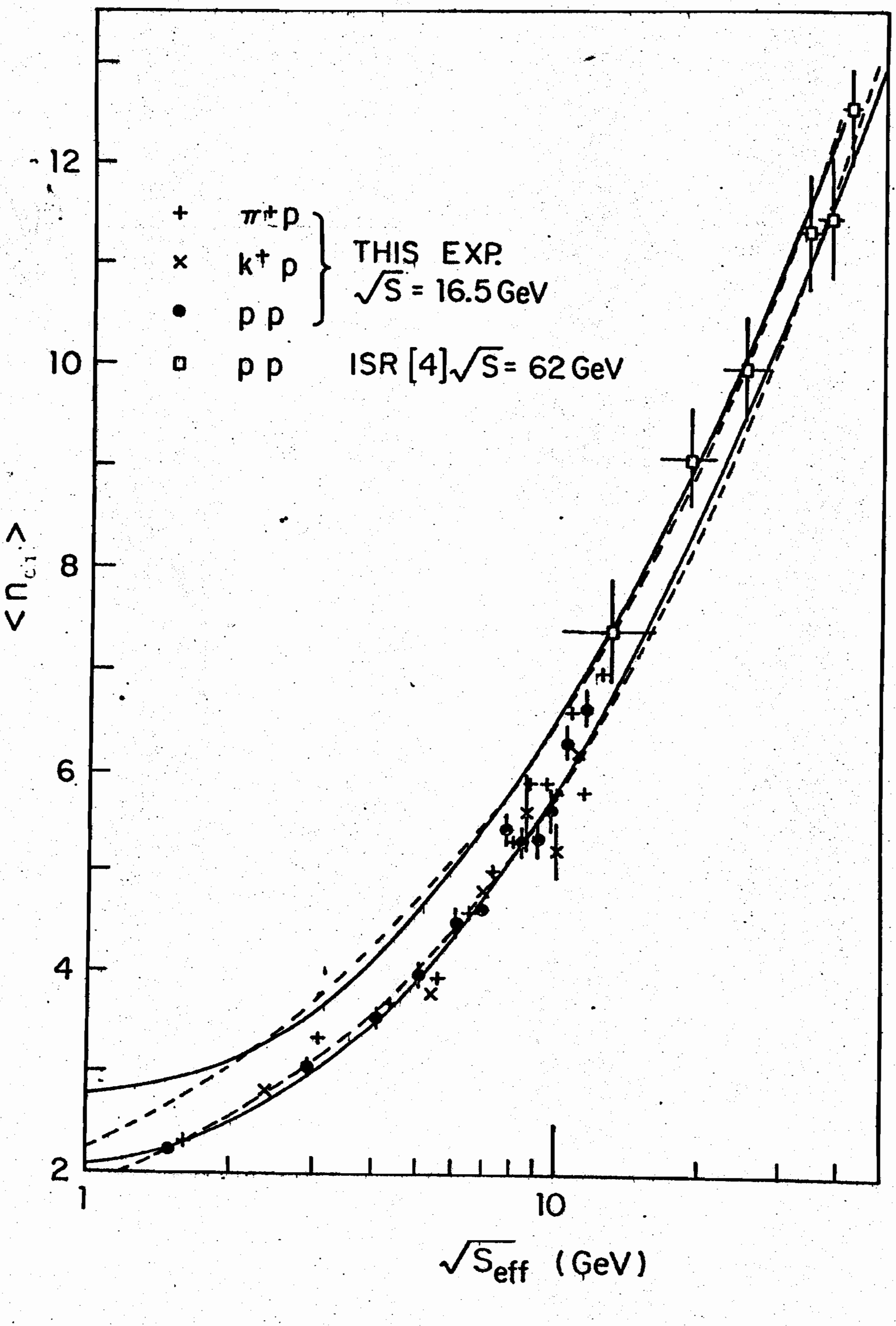

+ π+p
× k+ p
● p p
THIS EXP. √S = 16.5 GeV
□ p p ISR [4] √S = 62 GeV
12
10
8
6
4
2
<n_ch>
1
10
√S_eff (GeV)

Fig. 1a

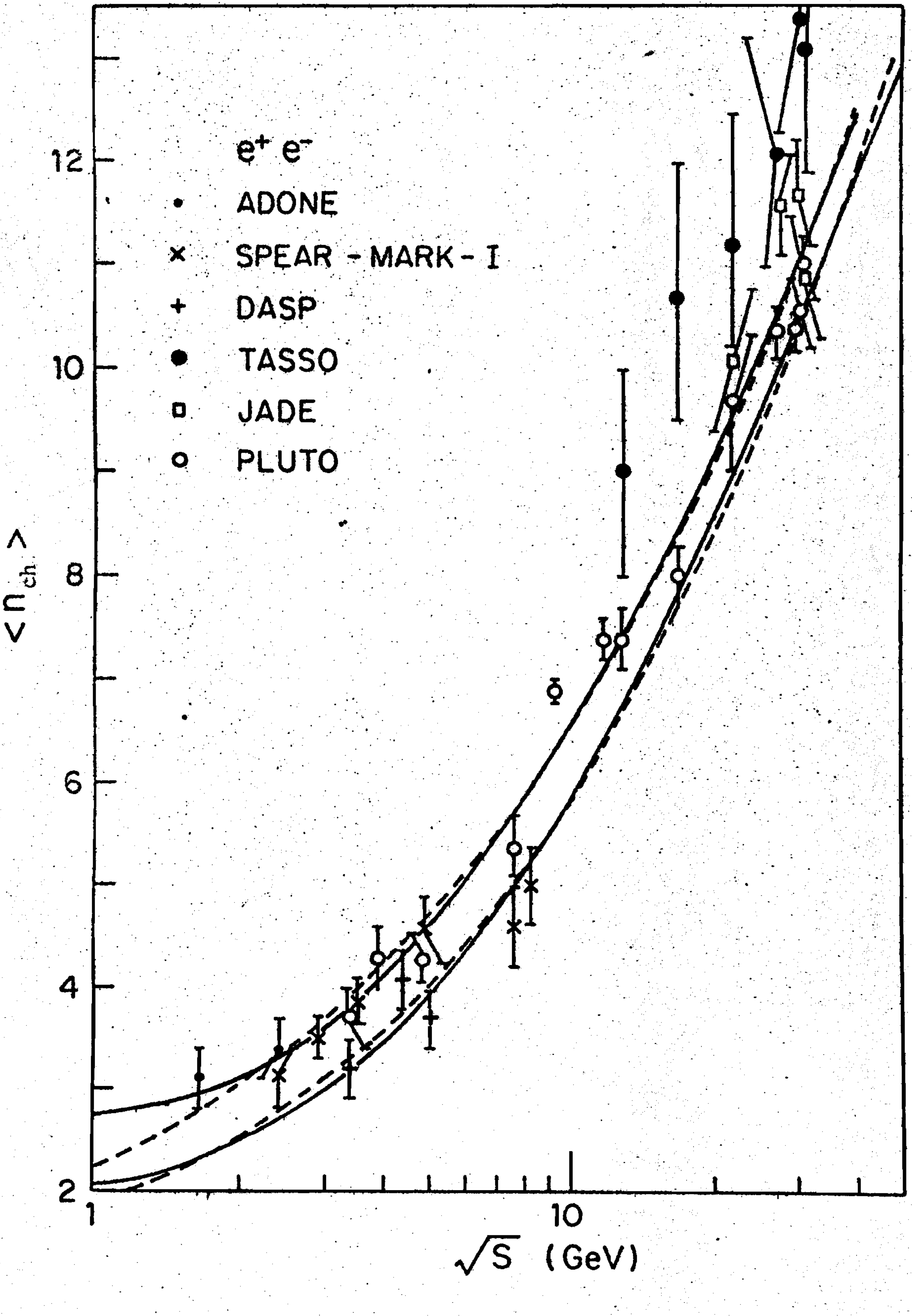
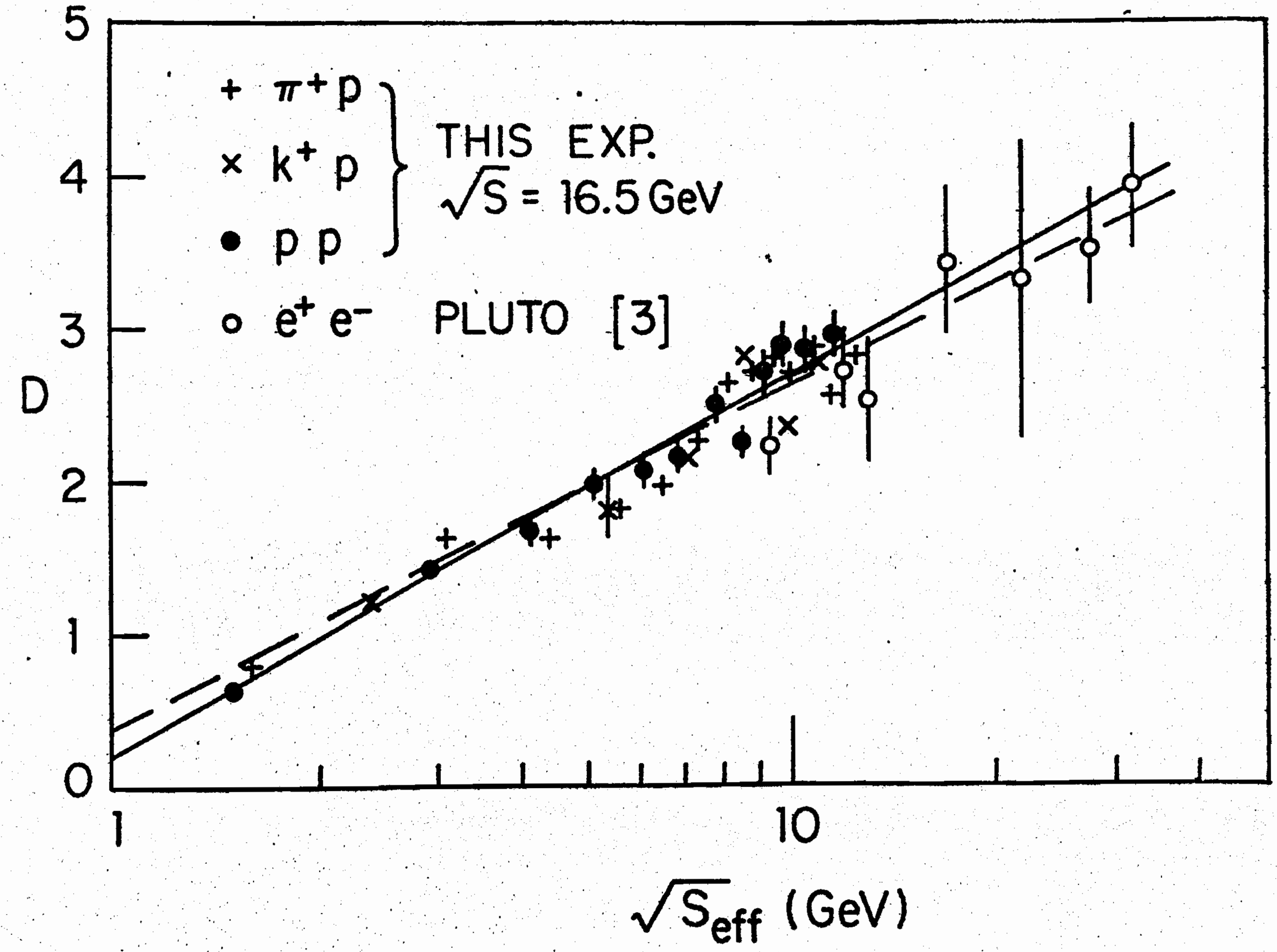

e^+e^-
• ADONE
× SPEAR - MARK - I
+ DASP
● TASSO
□ JADE
○ PLUTO
$<n_{ch}>$
2
4
6
8
10
12
1
10
$\sqrt{S}$ (GeV)

Fig. 1b



5
4
3
2
1
0
D
1
10
$\sqrt{S_{eff}}$ (GeV)
+ $\pi^+ p$
× $k^+ p$
● p p
THIS EXP.
$\sqrt{S}$ = 16.5 GeV
○ $e^+ e^-$ PLUTO [3]

Fig. 2