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GENERAL PROPERTIES OF HADRON-NUCLEUS REACTION MULTIPLICITIES

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General properties of hadron-nucleus reaction multiplicities.

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A unification of the description of charged particle multiplicities in hadron-nucleus reactions is discussed. It is shown that all available shower particle multiplicity data in hadron--nucleus reactions are compatible with the formula

$$R = \langle n_s(h,A)\rangle / \langle n_{ch}(h,p)\rangle = (0.12+0.90\langle\nu\rangle)+(1.53-2.29\langle\nu\rangle)(\langle n_{ch}(h,p)\rangle)^{-1}$$

1. Introduction.

In this note we show that there seems to be basically simple common features of the multiplicity data for all energies and all nuclei. In particular we show that the shower particle multiplicity stemming from the interaction of a hadron h (h = proton or pion) on a fixed nucleus A, $\langle n_s(h,A)\rangle$, is a linear function (with energy independent coefficients) of the corresponding charged particle multiplicity in hadron-proton interactions $\langle n_{ch}(h,p)\rangle$. With regard to the dependence on the mass number A we show that $\langle n_s(h,A)\rangle$ is a linear function of $\langle\nu\rangle$, i.e. the effective nuclear size penetrated by the projectile. The combined formula

$$\langle n_s(h,A)\rangle = 1.53 + \langle n_{ch}(h,p)\rangle(0.12+0.90\langle\nu\rangle) - 2.29\langle\nu\rangle \qquad (1)$$

describes within a few per cent all the shower particle multiplicity data in the energy-range 1-400 GeV (for proton projectiles) and 50-200 GeV (for pion projectiles) as well as the dependence upon the mass number A.

2. Parameterisation of the multiplicities.

Fig. 1 shows $\langle n_s(p,Em)\rangle$ from emulsion-experiments in the interval 1-400 GeV versus $\langle n_{ch}(p,p)\rangle$. It is evident that the experimental data fall along a straight line and we obtain

$$\langle n_s(p,Em)\rangle = (2.34\pm0.03)(\langle n_{ch}(p,p)\rangle-5.42) + (8.56\pm0.06) \qquad (2)$$

The fact that the line in Fig. 1 does not go through the origin explains why $R = \langle n_s(p,Em)\rangle/\langle n_{ch}(h,p)\rangle$ must be energy dependent. This energy dependence is shown in Fig. 2, where eq. (2) divided with $\langle n_{ch}(p,p)\rangle$ is exhibited and compared with p-Em data (black points).

All current models predict that $\langle n_s\rangle$ will increase with increasing $\langle\nu\rangle$ and some of the models predict a linear increase. In Fig. 3 $\langle n_s(p,Em)\rangle$ is plotted in different N_g-bins versus $\langle\nu(N_g)\rangle$ for different energies. N_g is the number of recoiling target protons, i.e. protons in the energy range 30-400 MeV. $\langle\nu(N_g)\rangle$ was calculated in accordance with the method described in ref. [4]. However, our correlation between $\langle\nu(N_g)\rangle$ and N_g is slightly different from the one given in ref. [4] since we have improved the method to estimate the ν-distribution. This estimation is based on a Monte-Carlo calculation where we use randomly generated nucleons in a Woods-Saxon potential bombarded with a randomly generated hadron beam. The different experimental data are indeed for each energy well described by

straight lines. There is also a linear dependence between $d\langle n_s\rangle/d\langle\nu\rangle$ and $\langle n_{ch}(p,p)\rangle$ [5].

Combining the results from Figs. 1 and 3 we obtain as the best fit:

$$\langle n_s(h,A)\rangle = (8.58\pm0.06) + (2.34\pm0.03)(\langle n_{ch}(h,p)\rangle-5.42) + \\ + (2.59\pm0.11)(\langle\nu\rangle-2.47) + \\ + (0.90\pm0.06)(\langle n_{ch}(h,p)\rangle-5.42)(\langle\nu\rangle-2.47) \qquad (3)$$

which is equivalent to eq. (1).

For $\nu = 1$ we obtain in this way

$$\langle n_s\rangle_{\nu=1} \sim \langle n_{ch}(p,p)\rangle - 0.75 \qquad (4)$$

The quantity $\langle n_s\rangle_{\nu=1}$ is close to the expected value for $\langle n_s(p,N)\rangle$, the shower particle multiplicity in proton-nucleon reactions i.e. the average number of singly charged particles with $\beta > 0.7$ in reactions where the target N is a proton or a neutron.

We have found that eq. (3) is in good agreement with the observed correlations between $\langle n_s\rangle$ and $\langle\nu(N_g)\rangle$ in π-Em reactions at 200 GeV. Eq. (3) also predicts within a few per cent all multiplicities of pA and πA reactions in the FNAL counter experiments performed by Busza et al. [3]. As an example we compare eq. (3) with π-A data in Fig. 4.

3. The R-dependence in hadron-nucleus reactions.

The energy dependence of R given by eq. (3) for emulsion, is

$$R_{Em} = \langle n_s(p,Em)\rangle / \langle n_{ch}(p,p)\rangle = R_o - R'/\langle n_{ch}(p,p)\rangle =$$

$$= 2.34 - 4.12/\langle n_{ch}(p,p)\rangle \qquad (5)$$

which is the curve shown in Fig. 2 for $\langle\nu\rangle = 2.47$.

The general expression of R_o is given by

$$R_o \approx 0.12 + 0.90 \langle\nu\rangle \qquad (6)$$

Fig. 2 also shows R predicted from eq. (3) for $\nu = 4$ and $\nu = 2$, and a comparison with data extrapolated by Busza et al. [5]. (open circles). The thin curves show that the shower-particle multiplicities are expected to decrease with increasing target mass at energies below ≈ 3.5 GeV. If the observed trend in the multiplicity data continues above 400 GeV the multiplicity ratio R approaches the asymptotic value $R \to R_o = 0.12 + 0.90 \langle\nu\rangle$. This value is not in agreement with most of the current models. For example the collective tube model or the multi-peripheral model predicts asymptotic values of $R \to 1$ independent of $\langle\nu\rangle$. We note that at very high energy it is the multiplicity in the central region of rapidity that completely dominates R. We then predict from the observations presented in this letter, that the charged particle multiplicity in the central region increases essentially as $\langle\nu\rangle$ times the corresponding multiplicity in hp-reactions, and not as $\frac{1}{2}(\langle\nu\rangle + 1)$, which has been suggested in many models. The reggeon model, however, predicts a behaviour for R_o (asymptotically in energy) like ν.

4. Conclusions.

We conclude that available high energy hadron-nucleus data do not show that R is constant above say 100 GeV. Instead we observe a continuous small increase of R also in the highest energy

range available at accelerators for h-A studies. If the trend observed continues also at higher energies the hadron-nucleus reaction data point to an asymptotic value $R \approx 0.9 \langle\nu\rangle$, independent of hadron-proton multiplicities (i.e. $\langle n_{ch}(h,p)\rangle$ but almost proportional to the thickness of the traversed nuclear matter i.e. $\langle\nu\rangle$. In the asymptotic range R measures the increase of the multiplicity in the central region of rapidity space. The observed ν-dependence deviates from most of the models where only the backward half of the rapidity space is affected by the target nucleus, i.e. $R = \frac{1}{2}(\langle\nu\rangle + 1)$.

Acknowledgements.

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Figure captions.

Fig. 1. The multiplicity of singly charged particles with $\beta > 0.7$ in proton-emulsion nucleus reactions, $\langle n_s(p,Em)\rangle$, as a function of the charged particle multiplicity observed in proton-proton reactions, $\langle n_{ch}(p,p)\rangle$. Data from refs. [1,2].

Fig. 2. $R = \langle n_s(p,Em)\rangle/\langle n_{ch}(p,p)\rangle$ as a function of the incident proton energy. The curves are estimated from eq. 3. Filled circles are emulsion data [1,2] and open circles are from ref. [3].

Fig. 3. $\langle n_s\rangle$ as a function of the number of encounters $\langle \nu(N_g)\rangle$ between the incident proton and the target nucleons calculated from the multiplicity of recoiling protons, i.e. N_g. The experimental data are from ref. [2].

Fig. 4. Comparison between eq. (3) and π-A multiplicities observed by Busza et al. [3].

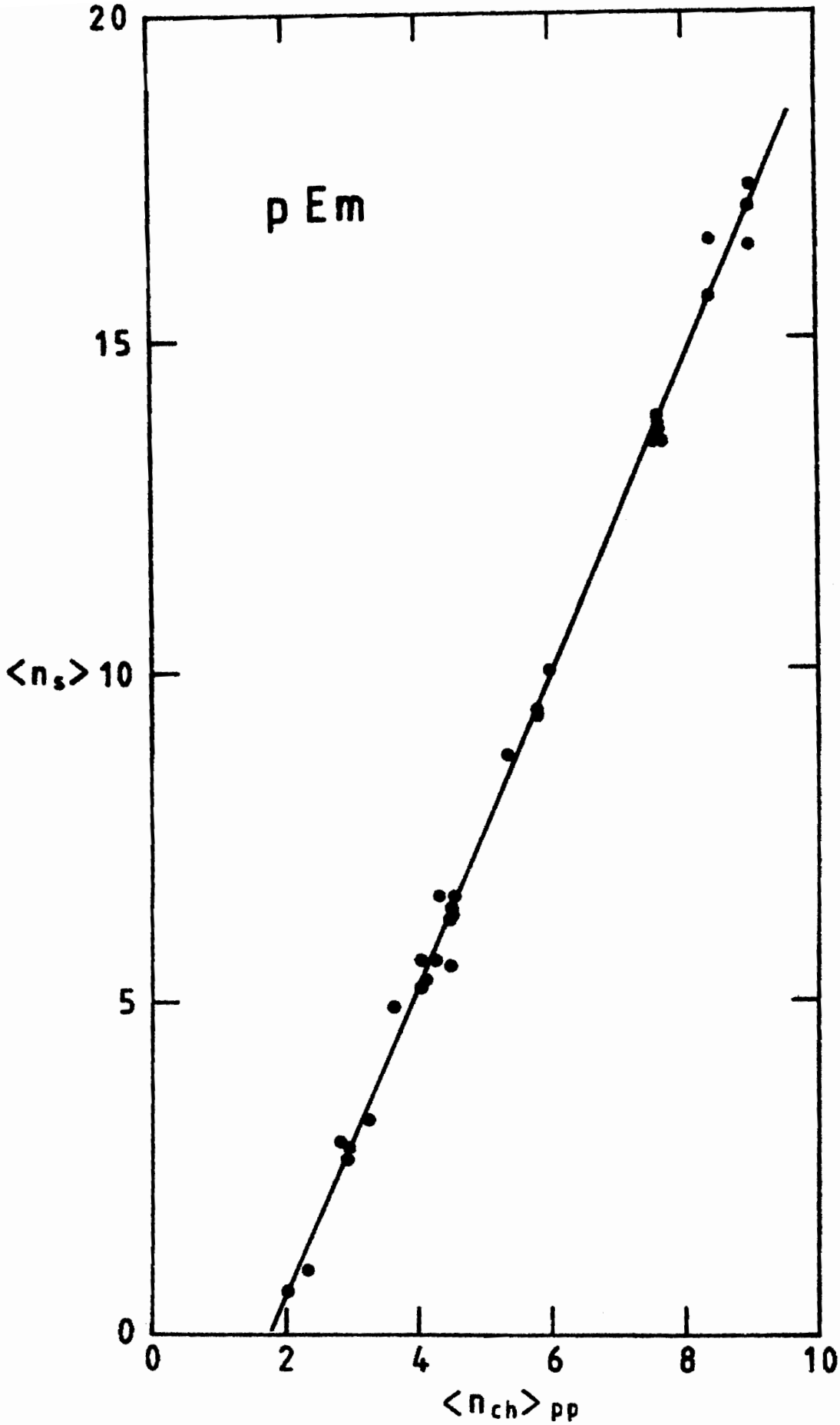


Fig. 1

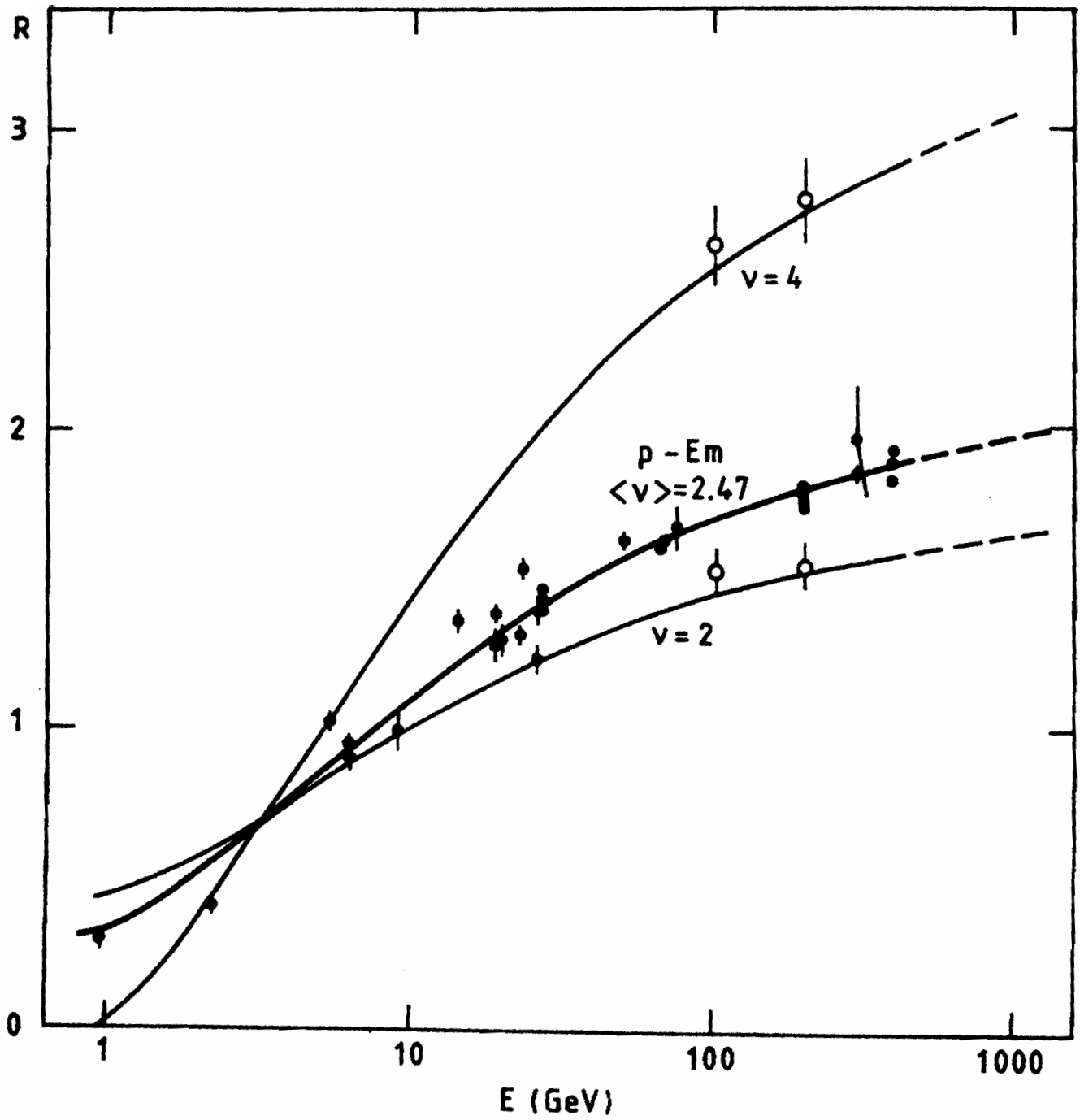
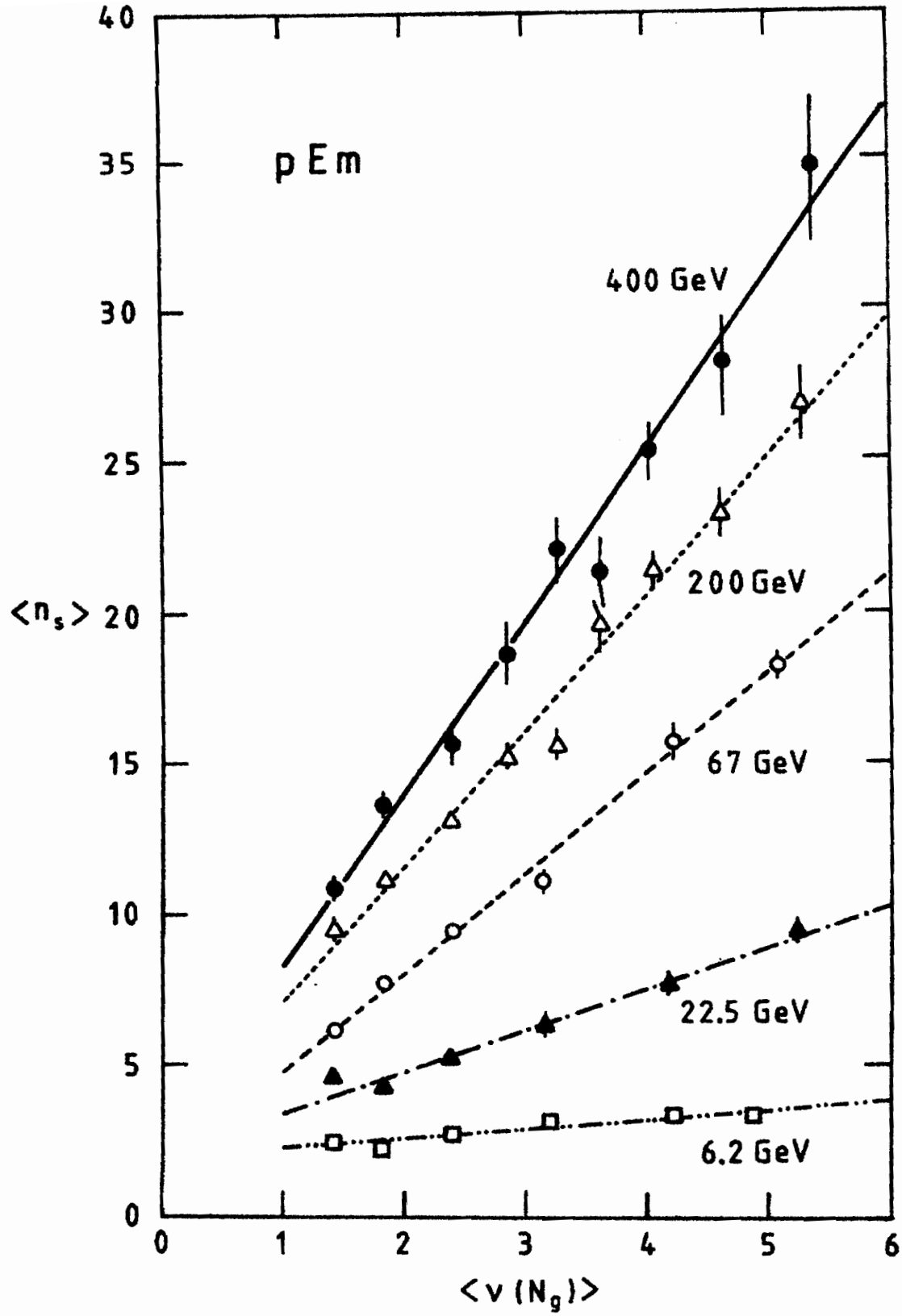


Fig. 2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200 GeV
67 GeV
22.5 GeV
6.2 GeV
<n_s>
<ν (N_g)>
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6

Fig. 3

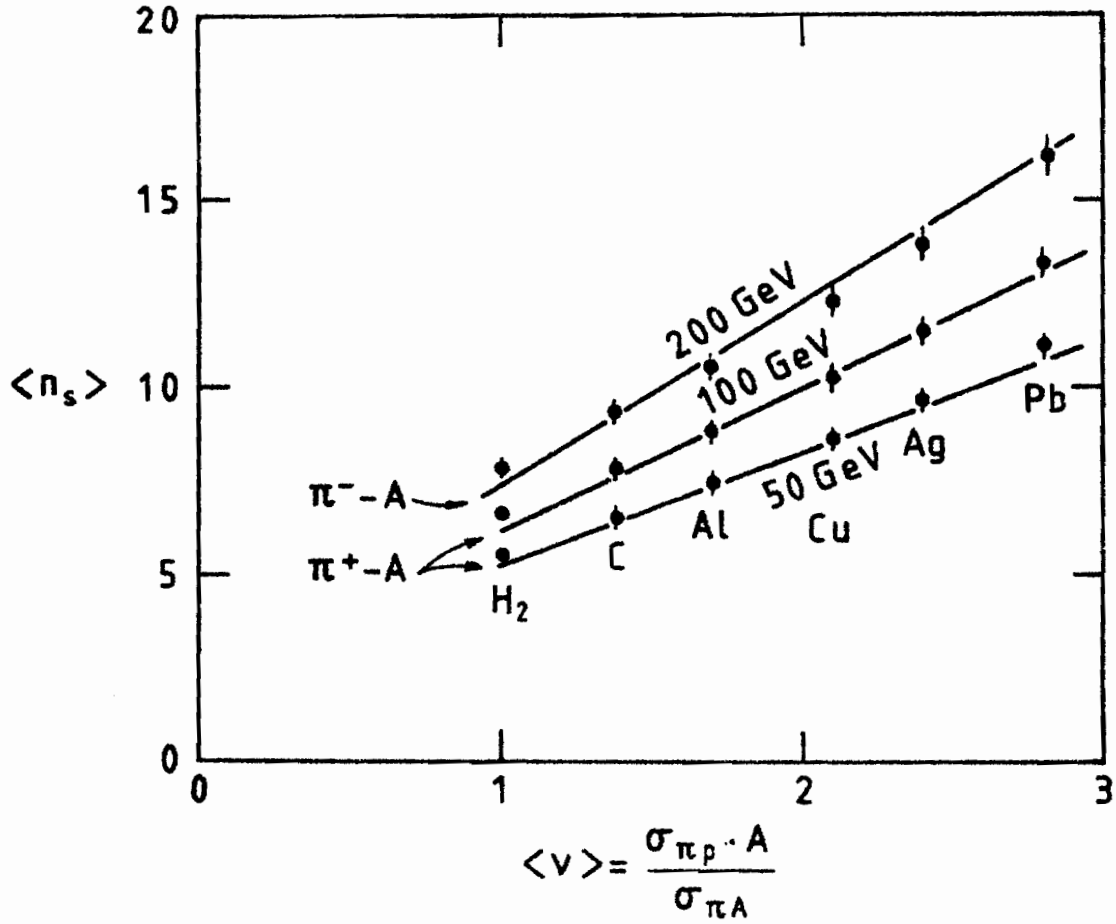
20
15
10
5
0
$\langle n_s \rangle$
0
1
2
3
200 GeV
100 GeV
50 GeV
$\pi^- - A$
$\pi^+ - A$
H_2
C
Al
Cu
Ag
Pb
$\langle \nu \rangle = \frac{\sigma_{\pi p} \cdot A}{\sigma_{\pi A}}$

Fig. 4

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