AVERAGE MULTIPLICITIES OF CHARGED PARTICLES IN MESON-PROTON AND PROTON-PROTON COLLISIONS

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It is shown that existing data are consistent with a constant difference of about 0.2 units between average multiplicities of charged particles in meson-proton and proton-proton collisions for $p_{LAB} \gtrsim 20$ GeV/c.

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The purpose of this paper is twofold. Firstly, energy dependence of the average multiplicity of charged particles, $\langle n_{ch} \rangle$, in $\pi^{\pm}p$, $K^{\pm}p$, pp, pn and $\pi^{\pm}n$ interactions is studied. Secondly, a new compilation of experimental results concerning $\langle n_{ch} \rangle$ is provided to replace the compilation by Albini et al. [1] published 8 years ago and by now largely outdated.

The difference in $\langle n_{ch} \rangle$ in πp and pp collisions has been analyzed in several papers. The naive quark picture in which a) particles are produced by the collision of a single quark from the beam with a single quark from the target and b) the value of $\langle n_{ch} \rangle$ depends on the total energy in the quark-quark center of mass, gives $\Delta \langle n \rangle = \langle n_{ch} \rangle_{\pi p} - \langle n_{ch} \rangle_{pp} \approx 0.7$ independent of the collision energy [2]. Other more realistic versions of the quark model [3–5] give $\Delta \langle n \rangle \approx 0.2$ to 0.4. On the other hand arguments based on the AGK cutting rules predict a cross-over of the πp and pp multiplicities at $s \approx 800$ GeV^2 [6].

Experimenters usually express the energy dependence of $\langle n_{ch} \rangle$ in the form of polynomials in $\ln s$ or $\ln E_a$, where $E_a = \sqrt{s} - m_{\text{beam}} - m_{\text{target}}$ is the center-of-mass energy available for production of new particles.

For pp interactions good data are available up to $s \lesssim 4000$ GeV^2 ($E_a \lesssim 60$ GeV). It has been found that the growth of $\langle n_{ch} \rangle$ with the energy in these interactions is faster than logarithmic and good fits were obtained [7] by using second order polynomials:

$$\langle n_{ch} \rangle = a_0 + a_1 \ln E_a + a_2 \ln^2 E_a \tag{1a}$$

or

$$\langle n_{ch} \rangle = b_0 + b_1 \ln s + b_2 \ln^2 s \tag{1b}$$

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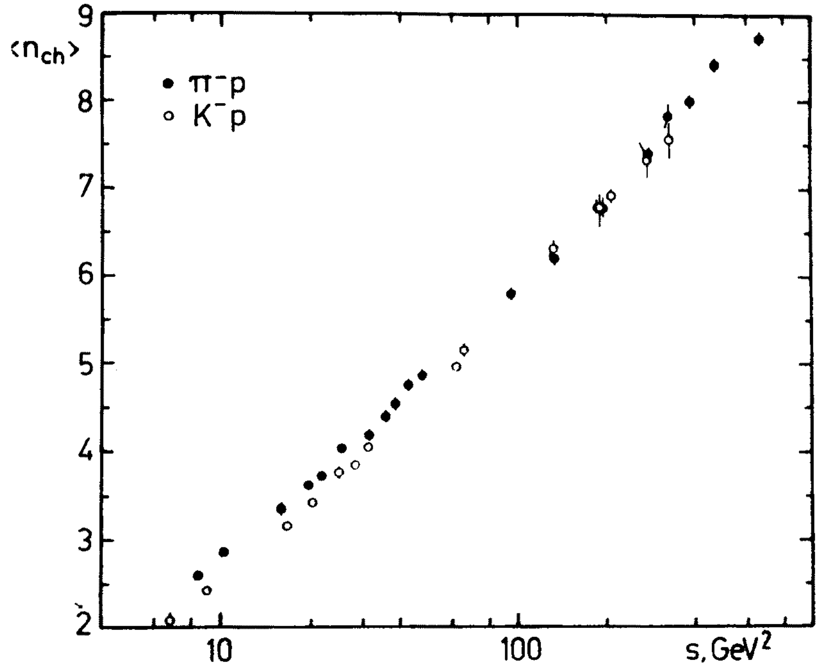
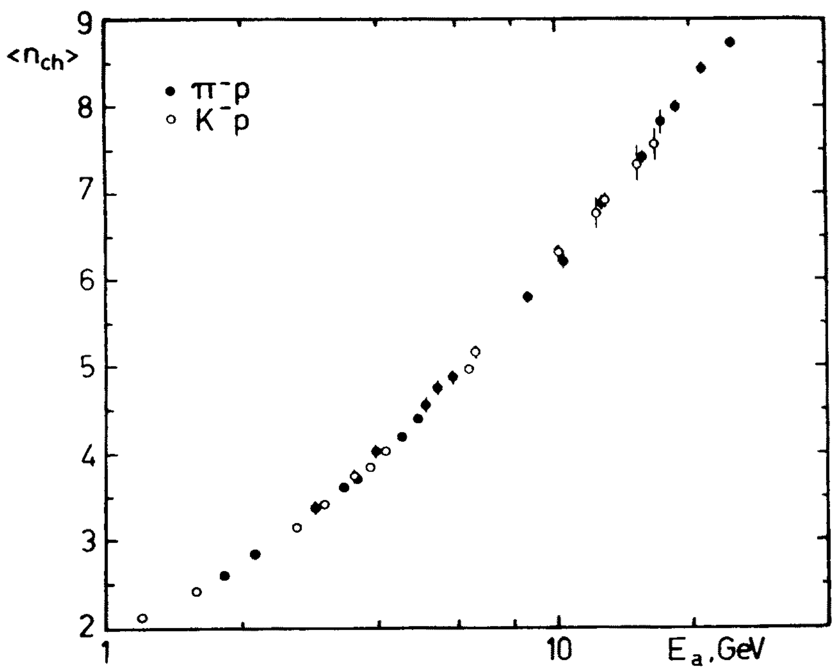


a



b

Fig. 1a). Average multiplicity of charged particles in π^-p and K^-p interactions (Tables II and IV) as a function of ln s. b) The same data plotted as a function of E_a

Data for meson-proton interactions are available in a more limited energy range, $s \lesssim 700\ \mathrm{GeV}^2$ ($E_a \lesssim 25$ GeV). Fits of the form (1) to $\langle n_{ch} \rangle$ in πp or Kp interactions usually give coefficients of quadratic terms smaller than in the pp case (see e.g. [8, 9]). Therefore by using (1) for extrapolation to very high energies one gets the result that meson-proton reactions would produce smaller $\langle n_{ch} \rangle$ than proton-proton collisions in agreement with [6]; such a result is however rather unlikely in a quark model. Because of the limited energy

TABLE I

Average multiplicity of charged particles in pp interactions

p_{LAB}, GeV/c	E_a, GeV	$\langle n_{ch} \rangle$	Ref.
2.8	0.83	2.22±0.01	[10]
3.7	1.11	2.35±0.02	[11]
4.0	1.20	2.54±0.03	[12]
5.5	1.62	2.72±0.02	[13]
6.6	1.90	2.86±0.03	[14]
6.9	1.97	2.93±0.04	[15]
10	2.66	3.22±0.06	[16]
12	3.05	3.43±0.03	[17]
12 9	3.22	3.66±0.07	[18]
18	4.08	4.04±0.08	[18]
19	4 24	4.02±0 02	[19]
21.1	4.56	4.30±0.09	[18]
24	4.96	4.25±0.03	[17]
24.1	4.98	4.46±0.09	[18]
28.4	5.54	4 60±0.10	[18]
28.5	5.55	4.58±0.07	[20]
35.7	6.41	4,78±0.04	[21]
50	7.90	5.36±0.10	[22]
60	8.81	5.60±0.09	[23]
69	9.58	5.85±0.09	[24]
100	11.88	6.49±0.11	[25]
100	11.88	6.37±0.06	[2]
100	11.88	6.44±0.17	[26]
102	12.02	6.32±0.07	[27]
147	14.79	7.02±0.05	[8]
175	16.29	7.54±0.15	[26]
205	17.78	7.68±0.07	[28]
293	21.53	8.12±0.08	[7]
303	22.00	8.86±0.16	[29]
303	22.00	8.50±0.12	[30]
400	25.55	9.14±0.12	[31]
405	25.72	8.99±0.14	[27]
405	25.72	8.77±0.12	[32]
492	28.47	9.54±0.12	[7]
1053	42.52	11.01±0.17	[7]
1473	50.72	11.77±0.10	[7]
2068	60.42	12.70±0.12	[7]

TABLE II

Average multiplicity of charged particles in π^{-}p interactions

p_{LAB}, GeV/c	E_a, GeV	$\langle n_{ch} \rangle$	Ref.
4	1.82	2.60 ± 0.03	[33]
5	2.13	2.83 ± 0.03	[34]
8.1	2.91	3.37 ± 0.06	[35]
10	3.36	3.61 ± 0.03	[36]
11.2	3.60	3.71 ± 0.04	[37]
13	3.95	4.02 ± 0.08	[38]
16.2	4.52	4.19 ± 0.05	[39]
18.5	4.89	4.39 ± 0.05	[35]
20	5.12	4.54 ± 0.07	[38]
22	5.42	4.76 ± 0.10	[40]
25	5.84	4.86 ± 0.07	[41]
50	8.66	5.78 ± 0.04	[42]
70	10.42	6.20 ± 0.07	[43]
100	12.65	6.79 ± 0.08	[44]
100	12.65	6.79 ± 0.11	[26]
147	15.56	7.40 ± 0.04	[45]
175	17.07	7.83 ± 0.14	[26]
205	18.56	7.99 ± 0.06	[46]
250	20.60	8.43 ± 0.06	[47]
360	24.93	8.73 ± 0.04	[48]

range over which these fits are performed the values of coefficients in polynomial formulas are probably much influenced by the trend of very low energy data.

In this paper a different method of comparing $\langle n_{ch} \rangle$ in meson-proton and proton-proton interactions is used. Instead of attempting fits of the form (1) separately for each reaction the energy dependence is studied of the difference $\Delta \langle n \rangle$ between the measured values of $\langle n_{ch} \rangle$ for meson-proton collisions and the values predicted by the fit to proton-proton data at the same E_a. Available energy E_a is used for the comparison instead of s because it accounts for the difference in masses of the interacting particles and thus removes trivial differences in the energy dependence at small values of s, as illustrated in Fig. 1.

The values of the average multiplicity of charged particles in pp, πp and Kp interactions are listed in Tables I–V. In the selection of data all less reliable results (emulsion, propane chambers) used by Albini et al. [1] were discarded and the preliminary estimates were replaced by the final values. Compared with [1], the lists in Tables I–V represent a twofold increase in the number of "good" data obtained on hydrogen target.

The fit of the form (1a) to the pp data (Table I) gave the result (for $p_{LAB} \geqslant 4$ GeV/c)

$$a_0 = 2.47 \pm 0.02, \quad a_1 = 0.29 \pm 0.03, \quad a_2 = 0.528 \pm 0.008, \quad \chi^2/\text{NDF} = 1.67.$$

It was found, however, that by discarding two points at 293 GeV [7] and 303 GeV [29] with the largest contribution to the value of χ^2/NDF, the fit was considerably improved (χ^2/NDF $= 1.27$) while the parameters remained practically the same:

$$a_0 = 2.47 \pm 0.02, \quad a_1 = 0.29 \pm 0.03, \quad a_2 = 0.530 \pm 0.009 \qquad (2)$$

TABLE III

Average multiplicity of charged particles in π^+p interactions

p_{LAB}, GeV/c	E_a, GeV	$\langle n_{ch} \rangle$	Ref.
1.60	0.90	2.33 ± 0.03	[49]
2.08	1.12	2.63 ± 0.03	[50]
2.75	1.39	2.83 ± 0.05	[51]
3.54	1.67	3.03 ± 0.02	[52]
4	1.82	3.06 ± 0.04	[53]
4.1	1.85	3.06 ± 0.02	[54]
5	2.13	3.30 ± 0.03	[55]
7	2.67	3.62 ± 0.07	[56]
8	2.91	3.71 ± 0.02	[57]
11.8	3.72	4.07 ± 0.02	[58]
15	4.31	4.48 ± 0.03	[59]
16	4.48	4.49 ± 0.02	[60]
18.5	4.89	4.68 ± 0.10	[35]
23	5.56	4.79 ± 0.03	[61]
32	6.73	5.21 ± 0.06	[62]
50	8.66	5.89 ± 0.06	[42]
60	9.58	6.23 ± 0.10	[23]
100	12.65	6.62 ± 0.07	[2]
100	12.65	6.80 ± 0.14	[25]
100	12.65	6.75 ± 0.16	[26]
147	15.56	7.41 ± 0.04	[8]
175	17.07	7.55 ± 0.21	[26]
200	18.32	8.10 ± 0.10	[63]

TABLE IV

Average multiplicity of charged particles in K^-p interactions

p_{LAB}, GeV/c	E_a, GeV	$\langle n_{ch} \rangle$	Ref.
3	1.18	2.07 ± 0.02	[64]
4.2	1.58	2.41 ± 0.02	[65]
8.2	2.65	3.14 ± 0.04	[66]
10.1	3.05	3.41 ± 0.02	[67]
12.6	3.55	3.75 ± 0.08	[68]
14.3	3.86	3.84 ± 0.02	[70]
16	4.15	4.03 ± 0.04	[67]
32.1	6.40	4.96 ± 0.02	[71]
33.8	6.60	5.16 ± 0.07	[72]
70	10.08	6.31 ± 0.09	[73]
100	12.31	6.76 ± 0.18	[26]
110	12.97	6.91 ± 0.07	[9]
147	15.21	7.33 ± 0.21	[45]
175	16.72	7.56 ± 0.18	[26]

TABLE V

Average multiplicity of charged particles in K+p interactions

p_{LAB}, GeV/c	E_a, GeV	$\langle n_{ch}\rangle$	Ref.
1.96	0.79	2 30±0.04	[74]
3	1.18	2.57±0 03	[75]
3.5	1.35	2.63±0.02	[75]
5	1.82	2.93±0.03	[75]
8.2	2.65	3.39±0.05	[75]
10	3.03	3.65±0.04	[76]
12.7	3.57	4.03±0.13	[56]
16	4.15	4.12±0.03	[77]
32	6.39	5.02±0.02	[78]
70	10 08	6 14±0.03	[79]
100	12.31	6 65±0.31	[80]
100	12.31	6.95±0.25	[26]
147	15.21	7.09±0.09	[8]
175	16.72	7.61±0.37	[26]
200	17.97	8.10±0.22	[63]

Fit (2) was thus accepted as the best representation of the pp data. Then, for each meson-proton (Mp) result (Tables II–V) the value of $\langle n_{ch}\rangle^c$ expected for pp collision was computed using (2) and the difference

$$\Delta\langle n\rangle = \langle n_{ch}\rangle_{Mp} - \langle n_{ch}\rangle^c_{pp} \tag{3}$$

was calculated with the error taken, for simplicity, only from $\langle n_{ch}\rangle_{Mp}$. The values of $\Delta\langle n\rangle$ are displayed as a function of E_a in Figs. 2 and 3.

For π^-p and K^-p interactions $\Delta\langle n\rangle$ is negative at very low values of E_a (Fig. 2) because of the charge annihilation component (zero-prongs). However for $E_a \gtrsim 5$ GeV $\Delta\langle n\rangle$ is systematically positive for all meson-proton reactions except for a single π^-p point at $E_a \approx 25$ GeV, i.e. $p_{LAB} = 360$ GeV/c [48] which does not agree with the trend of the remaining data and probably is biased with a large systematic error[1].

The fit of the form $\Delta\langle n\rangle = a + b \cdot E_a$ to 35 πp and Kp points for $E_a > 5$ GeV (excluding the 360 GeV/c result) gave $a = 0.19 \pm 0.02$, $b = -0.0006 \pm 0.0023$, χ^2/NDF = 1.4 (By including the 360 GeV/c point the fit was much worse (χ^2/NDF = 2.4) and the parameters were $a = 0.26 \pm 0.02$, $b = -0.0095 \pm 0.0017$).

Thus one may conclude that existing data for $\langle n_{ch}\rangle$ in πp and Kp interactions are consistent with an energy independent positive difference of about 0.2 units between $\langle n_{ch}\rangle$ in meson-proton and proton-proton collisions. In other words, the formula

$$\langle n_{ch}\rangle = 2.66 + 0.29 \ln E_a + 0.530 \ln^2 E_a$$

[1] The preliminary results from the EHS-NA22 Collaboration presented at the XIV Multiparticle Symposium at Lake Tahoe (June 1983) yield $\Delta\langle n\rangle = 0.25 \pm 0.09$ and 0.10 ± 0.14 for π^+p and K+p at 250 GeV/c ($E_a \approx 20$ GeV) in agreement with the data shown in Fig. 3.

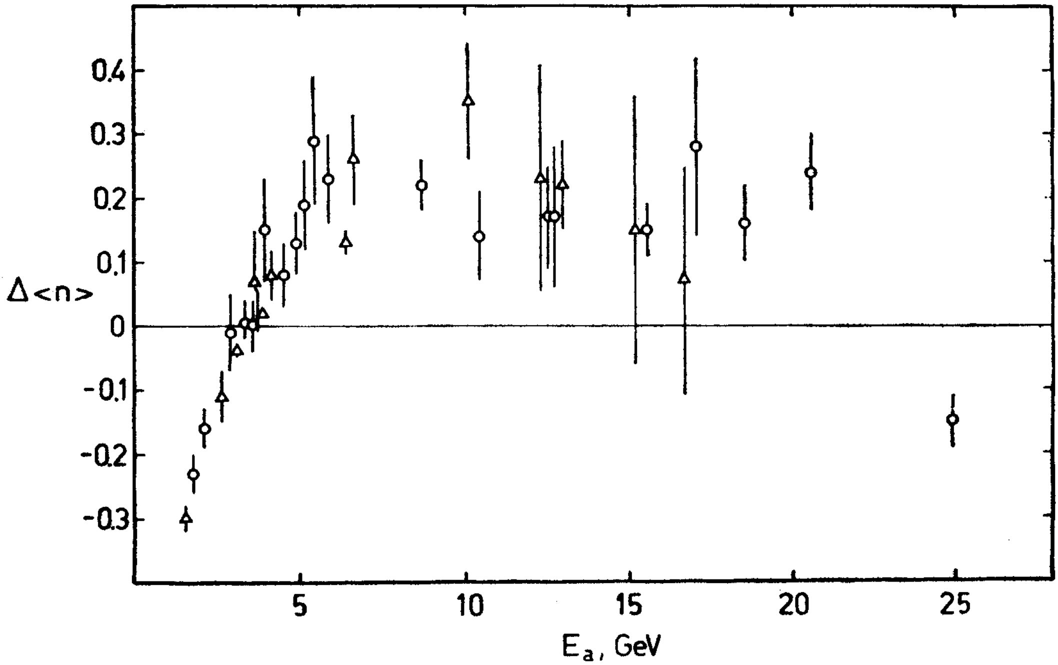


Fig. 2. Difference $\Delta\langle n\rangle$ between $\langle n_{ch}\rangle$ for $\pi^{-}p$ (circles) and $K^{-}p$ (triangles) reaction and the $\langle n_{ch}\rangle^{c}$ calculated from the fit (2) for pp interactions

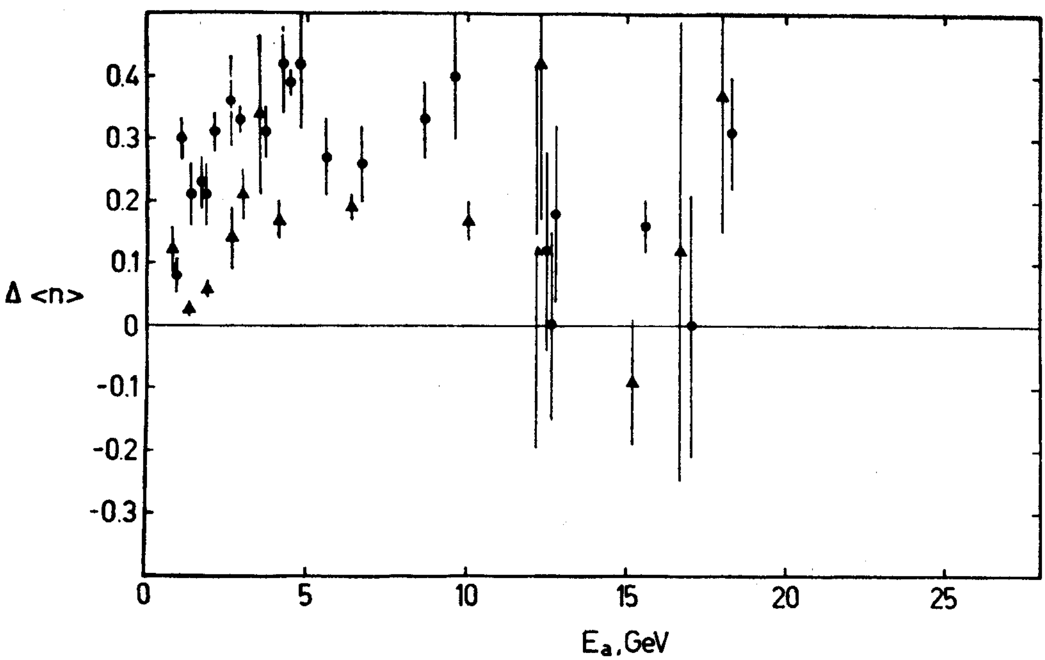


Fig. 3. Difference $\Delta\langle n\rangle$ between $\langle n_{ch}\rangle$ for $\pi^{+}p$ (circles) and $K^{+}p$ (triangles) reactions and the $\langle n_{ch}\rangle^{c}$ calculated from the fit (2) for pp interactions

gives a very good representation of all meson-proton average multiplicities of charged particles for $E_a \gtrsim 5$ GeV ($p_{\rm LAB} \gtrsim 20$ GeV/c).

There is little evidence for the possible cross-over of Mp and pp average multiplicities at $E_a \approx 30$ GeV as advocated in [6].

Similar analysis was done for interactions with neutrons. In this case results for $\langle n_{\rm ch}\rangle$ on a neutron target were derived mainly from experiments in deuterium or propane bubble chambers. Since in these analyses certain assumptions were involved the results (Tables VI and VII) should be treated with some caution.

The data for $\langle n_{\rm ch}\rangle$ in pn interactions (Table VI) were fitted with formula (1a). The results

$$a_0 = 2.06 \pm 0.04, \quad a_1 = 0.33 \pm 0.08, \quad a_2 = 0.533 \pm 0.026, \quad \chi^2/\mathrm{NDF} = 2.3 \tag{3}$$

indicate almost identical energy dependence of pn and pp data (2), the difference

$$\langle n_{\rm ch}\rangle_{\rm pp} - \langle n_{\rm ch}\rangle_{\rm pn} \sim 0.4$$

being connected with the proton-neutron charge exchange probability. The difference $\Delta\langle n\rangle$ of πn results (Table VII) and the fit (3) for pn collisions is plotted as a function of E_a in Fig. 4. Again the data display a constant difference of ~0.2 units compared to the fit (3). The fit $\Delta\langle n\rangle = a + bE_a$ yields $a = 0.29 \pm 0.05$, $b = -0.0044 \pm 0.0043$, $\chi^2/\mathrm{NDF} = 1.4$ in perfect agreement with the results for πp and Kp interactions.

To conclude: the average multiplicity of charged particles in meson-nucleon collision seems to be larger by $\Delta\langle n\rangle \approx 0.2$ units than the one in proton-nucleon collision at the same available energy (for $E_a \gtrsim 5$ GeV). This difference seems to be independent of E_a, although one can not exclude a very slow decrease of $\Delta\langle n\rangle$ with E_a. The results of the analysis presented in this paper demonstrate that contrary to the recent claim by Brick et al. [8] one can not get a common good fit to meson-proton and proton-proton multiplicities by using E_a instead of $\sqrt{s}$.

TABLE VI

Average multiplicity of charged particles in pn interactions

$p_{\rm LAB}$, GeV/c	E_a, GeV	$\langle n_{\rm ch}\rangle$	Ref.
3.1	0.92	2.04±0.06	[81]
3.8	1.15	2.11±0.06	[81]
4.4	1.31	2.20±0.06	[81]
5.1	1.50	2.36±0.07	[81]
11.6	2.98	2.94±0.06	[82]
19	4.24	3.53±0.12	[83]
28	5.49	4.38±0.10	[84]
100	11.88	6.20±0.11	[85]
195	17.32	7.56±0.09	[86]
200	17.54	7.36±0.09*	[87]
300	21.88	7.96±0.15*	[88]
400	25.55	8.57±0.12	[89]

* Values of $\langle n_{\rm ch}\rangle$ taken from [89].

TABLE VII

Average multiplicity of charged particles in π^+n and π^-n interactions

p_{LAB}, GeV/c	E_a, GeV	$\langle n_{ch} \rangle$	Ref.
5 (−)	2.13	2.67±0.22	[90]
15 (−)	4.31	3.99±0.05	[91]
21 (−)	5.27	4.48±0.07*	[92]
40 (−)	7.64	5.07±0.06	[93]
100 (−)	12.65	6.53±0.08	[94]
100 (+)	12.65	6.57±0.13	[85]
195 (+)	18.10	7.77±0.09	[86]
205 (−)	18.56	7.79±0.09*	[95]
360 (−)	24.93	8.85±0.12*	[96]

* Values of $\langle n_{ch} \rangle$ taken from [97].

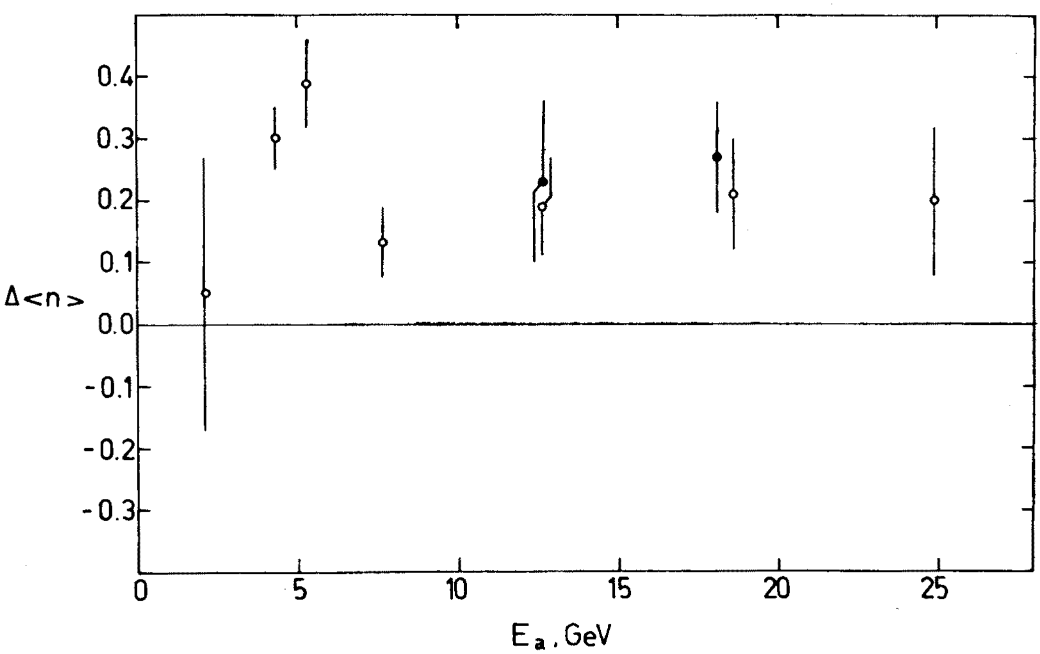


Fig. 4. Difference $\Delta\langle n \rangle$ between $\langle n_{ch} \rangle$ for π^-n (open circles) and π^+n (full circles) reactions and the $\langle n_{ch} \rangle^c$ calculated from the fit (3) for pn interactions

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