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FLUCTUATIONS IN THE HADRONIC TEMPERATURE IN pp, pα AND αα COLLISIONS AT ISR ENERGIES

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ABSTRACT

We present evidence for fluctuations of the average transverse momentum in pp, pα and αα collisions at ISR energies. In thermodynamical models, this is interpreted as fluctuations in the temperature of hadronic interactions. We find that the effect does not depend on the energy of the collision, however, the fluctuations are smaller for αp and αα reactions than for pp interactions.

1. INTRODUCTION Studies of the distributions of transverse momenta of particles produced in hadron-hadron reactions have shown that at low p_T they depend only weakly on energy and initial particles. The mean value of the transverse momentum is then one of a few universal variables used for the description of hadronic reactions. In thermodynamical models it is a measure of the temperature of hadron-hadron interactions. It is interesting to study whether all events of a given reaction correspond to the same average transverse momentum or if there are non-trivial variations from event to event.

In particular, it has been suggested [1] that a large transverse relative acceleration a between two interacting particles in high energy hadronic collisions is connected with the thermal emission of particles at a temperature T given by $kT = a/2\pi$, where k is the Boltzmann constant (units are $\hbar = c = 1$) [2,3]. In a simple geometrical model the acceleration a can be connected with an impact parameter b by the uncertainty principle. The average temperature is then related to an average impact parameter $\langle b \rangle$ between two particles: $\langle kT \rangle \sim 1/\langle b \rangle$. Due to variations in impact parameter, significant fluctuations must occur, event by event(*) [1]. Recently, evidence for such fluctuations has been presented for antinucleon-nucleon annihilations at low energies [4,5].

2. EXPERIMENT In this paper we present an analysis using high statistics data for pp, pα and αα collisions. The experiments were performed at the CERN Intersecting Storage Rings (ISR) using the Split Field Magnet (SFM) detector. The magnetic volume (with a maximum field strength of 1 T) is filled with Multiwire Proportional Chambers. The momenta of charged particles were measured in nearly the full solid angle of 4π steradians. The performance of the detector is described in previous publications [6]. These experiments used a "minimum bias" trigger, which essentially required the presence of at least one charged track in the detector. Some information about the data used in the following analysis is given in table 1.

(*) In some hadron-hadron collisions (e.g. Drell-Yan processes) there are no impact parameter variations. In these "point-like" reactions non-statistical fluctuations are not expected in the model considered in ref. [1].

Only charged tracks in the central region $|x| = |p_L/p_{Lmax}| < 0.3$, are considered(*). In this region there is no contribution from leading nucleons and inclusive single-particle transverse momentum distributions are well described by thermodynamical models [7]. Only well measured tracks have been used ($\Delta p/p < 30\%$).

3. ANALYSIS In calculating the average transverse momentum

$$\bar{p}_T = \frac{1}{n} \sum_{i=1}^{n} |p_T|_i ,$$

where n is the multiplicity of particles, for each event, one has to deal with the trivial statistical fluctuations which, for events with presently available multiplicities, dominate in the dispersion $D(\bar{p}_T) = (\langle\bar{p}_T^2\rangle - \langle\bar{p}_T\rangle^2)^{1/2}$ of this quantity. Brackets "<>" indicate averaging over all events. One can study these fluctuations of $\bar{p}_T$ by calculating the square of the dispersion $D_n^2(\bar{p}_T) = \langle\bar{p}_T^2\rangle_n - \langle\bar{p}_T\rangle_n^2$ for a fixed number n of charged particles in the central region and then extrapolating the results to infinite multiplicity. The statistical contribution to $D_n^2(\bar{p}_T)$ decreases with the number of particles as $1/n$. We assume that the non-statistical contribution to D_n^2 does not depend on multiplicity. Under this assumption the square of the normalized dispersion can be written in the following form

$$[D_n(\bar{p}_T)/\langle\bar{p}_T\rangle]^2 = A + B/n \qquad (1)$$

where A and B are parameters to be calculated from the data.

In fig. 1 $D_n^2(\bar{p}_T)$, normalized to the average transverse momentum $\langle\bar{p}_T\rangle$, is plotted for a few examples of the reactions analysed, together with linear fits of the form (1). The fits are very good. The fitted parameters A, B and χ^2 probabilities of fits for all reactions are given in table 2.

We observe non-zero values for A for all the reactions studied. The normalized dispersion for the "true" average transverse momentum distribution, $R = [D(\bar{p}_T)/\langle\bar{p}_T\rangle]_{n=\infty} = A^{1/2}$ gives a measure of the

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(*) To check the sensitivity of the observed effects to the well known sea-gull effect we have varied the definition of the central region. No dependence of the results obtained is observed for $|x| < x_c$, where x_c was varied from 0.05 to 0.5.

non-statistical fluctuations in $\bar{p}_T$. Values of R and values of dispersion $D(\bar{p}_T)$ extrapolated to infinite multiplicities are given in table 2. The systematic error was studied by using Monte-Carlo events and by making various cuts in the samples. We estimate that a 10% systematic error should be added to statistical errors for R and $D(\bar{p}_T)$ given in table 2, mainly due to losses of very low transverse momenta particles. In fig. 2 R is plotted as a function of c.m.s. energy $\sqrt{s_{NN}}$ per nucleon-nucleon collision. No dependence on energy is observed for pp and $\alpha\alpha$ interactions. The dispersion of the $\bar{p}_T$ distribution has a constant value of about 12% of the average transverse momentum $<\bar{p}_T>$ in pp reactions at high energies.

The value of R = 0.09 for $\alpha\alpha$ collisions is $\sim$ 30% lower than in pp interactions. This decrease corresponds approximately to the decrease expected for a superposition of two independent nucleon-nucleon collisions. We have simulated this effect using the highest statistics pp data at 63 GeV and calculating $\bar{p}_T$ for pairs of events taken together. The result is shown in fig. 2. Indeed, in $\alpha\alpha$ interactions, on the average, $\sim$ 1.8 nucleon-nucleon interactions take place [8]. However, increasing multiplicity corresponds also to an increasing number of nucleon-nucleon collisions [9]. Therefore, a non-linear decrease of D_n^2 with 1/n seems possible and formula (1) should not give an adequate description of the data. Within the statistical precision of the data, however, such an effect is not seen and the extrapolated value of R represents most likely an average behaviour.

The value of R for αp interactions is expected to fall between pp and $\alpha\alpha$ results. Since the error is relatively large, the experimental result is not inconsistent with this expectation.

The result obtained from $p\bar{p}$ annihilations at a laboratory momentum of 12 GeV/c is R = 0.18 + 0.02 [5] and could suggest a slightly wider $\bar{p}_T$ distribution in annihilation reactions than in pp scattering, but the present errors and the large difference of initial energies do not allow definite conclusions.

4. CONCLUSIONS In summary, we observe significant non-statistical event by event fluctuations in the average transverse momentum $\bar{p}_T$, which in the thermodynamical model can be interpreted as fluctuations in the temperature of hadronic interactions. We observe no dependence of these fluctuations on energy in the ISR energy range, as expected in the model [1]. In $\alpha\alpha$ and αp collisions the fluctuations are smaller than in pp interactions.

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TABLE CAPTIONS

Table 1 Data sets used in the analysis.

Table 2 Parameters A and B and χ^2 probabilities of the straight line fits of the formula (1). Also normalized ($R = A^{1/2}$) and absolute values of dispersion $D(\bar{p}_T)$ extrapolated to infinite multiplicity are given. The 10% systematic error should be added to the statistical errors given in the table.

TABLE 1

Reaction	C.m.s. energy per nucleon-nucleon collision [GeV]	Number of events
pp	30.8	29 707
pp	45.0	45 446
pp	52.0	18 032
pp	63.0	125 951
pα	44.0	34 410
αα	26.3	31 207
αα	31.2	36 499

TABLE 2

Reaction	$\sqrt{s_{NN}}$ [GeV]	A	B	P_{χ^2}	$R = A^{1/2}$	$D(\bar{p}_T)$ [MeV]
pp	30.8	0.0139 ± 0.0023	0.491 ± 0.015	0.72	0.118 ± 0.009	37.2 ± 2.8
pp	45.0	0.0143 ± 0.0017	0.458 ± 0.013	0.04	0.120 ± 0.008	41.5 ± 2.8
pp	52.0	0.0136 ± 0.0020	0.453 ± 0.016	0.08	0.117 ± 0.009	42.9 ± 3.3
pp	63.0	0.0133 ± 0.0007	0.425 ± 0.006	0.26	0.115 ± 0.004	42.3 ± 1.5
pα	44.0	0.0072 ± 0.0017	0.491 ± 0.017	0.68	0.085 ± 0.010	30.3 ± 3.6
αα	26.3	0.0074 ± 0.0013	0.465 ± 0.013	0.72	0.086 ± 0.007	30.4 ± 2.5
αα	31.2	0.0077 ± 0.0011	0.489 ± 0.012	0.29	0.088 ± 0.006	30.3 ± 3.6

FIGURE CAPTIONS

Fig. 1 (a) Normalized dispersion squared $[D_n(\bar{p}_T)/\langle\bar{p}_T\rangle]^2$ of the average (event by event) transverse momentum $\bar{p}_T$ distribution for n charged particles in the central region ($|x| < 0.3$) of pp reactions at $\sqrt{s_{NN}} = 63$ GeV as a function of 1/n. The straight line is a fit of the formula $[D_n(p_T)/\langle p_T\rangle]^2 = A + B/n$ to the data.

(b) Equivalent with fig. 1(a), but now for charged particles in the central region of αα reactions at c.m.s. energy per nucleon-nucleon collision $\sqrt{s_{NN}} = 31.2$ GeV.

(c) Equivalent with fig. 1(a), but now for αp reactions at c.m.s. energy per nucleon-nucleon collision $\sqrt{s_{NN}} = 44$ GeV.

Fig. 2 Normalized dispersion $R = D(\bar{p}_T)/\langle\bar{p}_T\rangle$ of average transverse momentum distribution for pp, pα and αα reactions as a function of c.m.s. energy per nucleon-nucleon collision $\sqrt{s_{NN}}$. Contributions to R from statistical fluctuations of $\bar{p}_T$ are removed by the method described in the text.

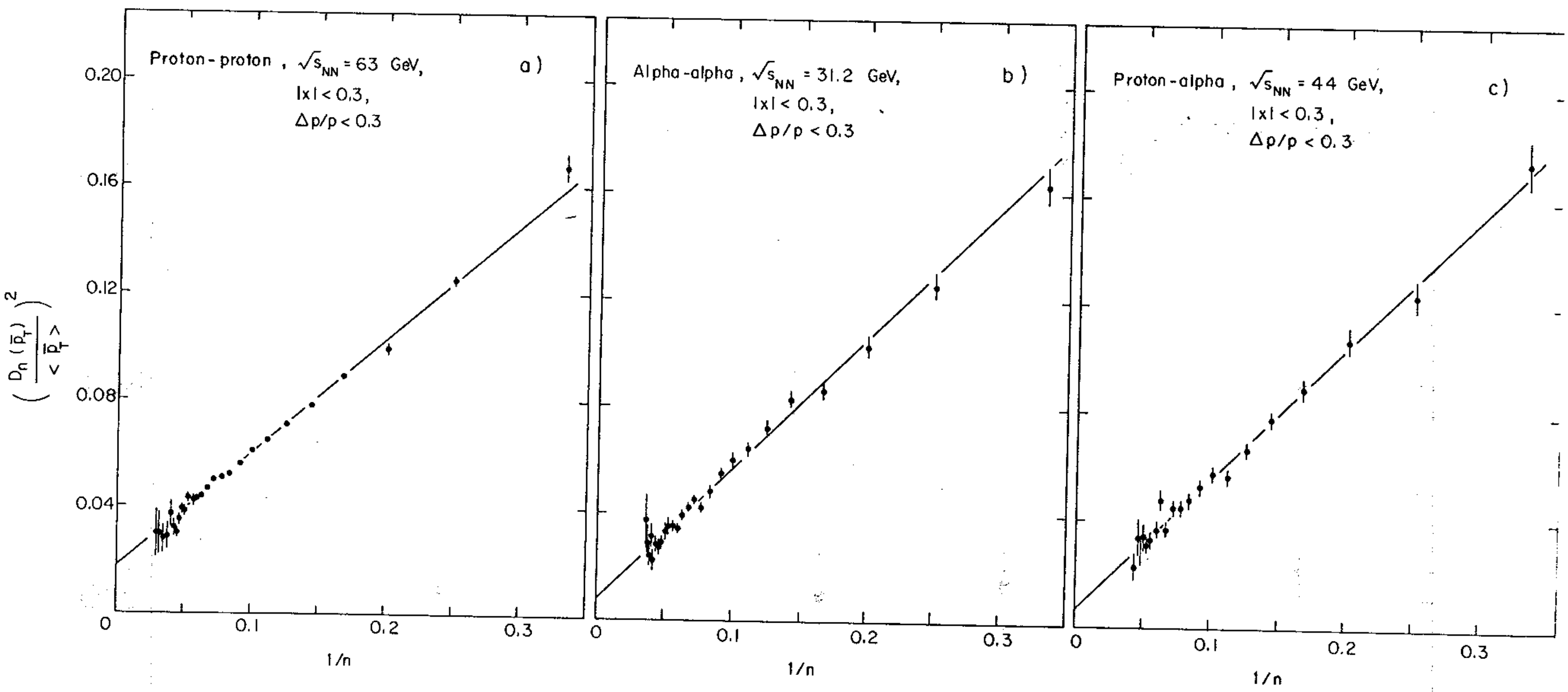
Proton-proton, $\sqrt{s_{NN}} = 63$ GeV,
$|x| < 0.3$,
$\Delta p/p < 0.3$
a)
Alpha-alpha, $\sqrt{s_{NN}} = 31.2$ GeV,
$|x| < 0.3$,
$\Delta p/p < 0.3$
b)
Proton-alpha, $\sqrt{s_{NN}} = 44$ GeV,
$|x| < 0.3$,
$\Delta p/p < 0.3$
c)
$\left(\frac{D_n(\bar{p}_T)}{\langle \bar{p}_T \rangle} \right)^2$
0.20
0.16
0.12
0.08
0.04
0
0.1
0.2
0.3
1/n

Fig. 1

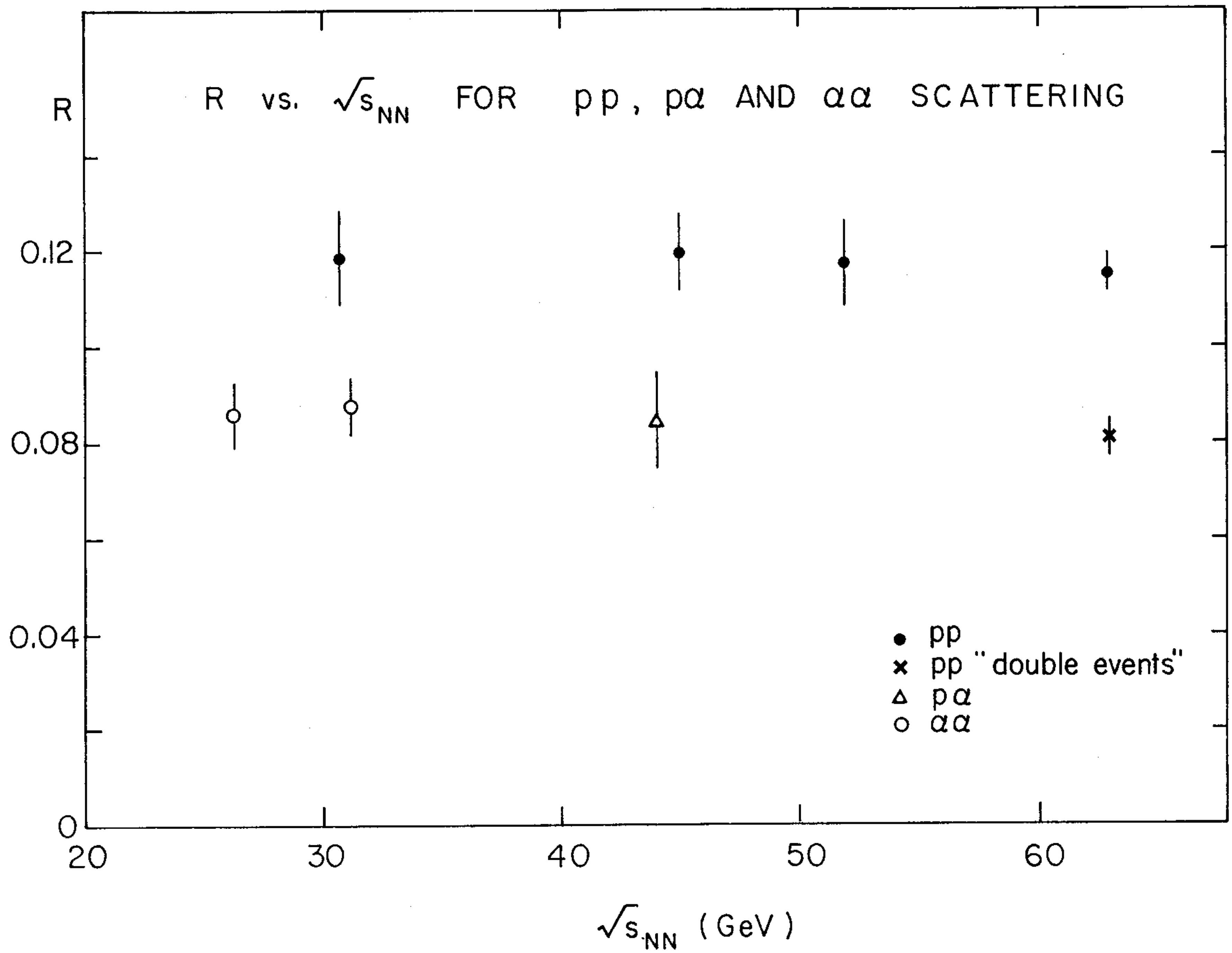
R vs. √s_NN FOR pp, pα AND αα SCATTERING
R
0.12
0.08
0.04
0
20
30
40
50
60
pp
pp "double events"
pα
αα
√s_NN (GeV)

Fig. 2