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# STUDY OF INELASTIC $\alpha\alpha$ AND $\alpha p$ COLLISIONS IN THE CERN ISR

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## ABSTRACT

Inelastic $\alpha\alpha$ and $\alpha p$ interactions have been measured at the CERN Intersecting Storage Rings at centre-of-mass energies of 125 and 88 GeV, respectively, with the Split Field Magnet Detector. Charged-particle densities and two-particle correlation functions in the central rapidity region are reported and compared with corresponding results for pp interactions and with theoretical predictions.

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## 1. INTRODUCTION

A general introduction to the physics in the ISR, and in particular to the physics with $\alpha$ particles, will be given by Jacob[1]. So I will make only two remarks as to what one hopes to learn from $\alpha\alpha$ and $\alpha p$ collisions in the ISR.

Firstly: with $\alpha$ particles in the CERN ISR we are entering a new energy regime for collisions involving nuclei. For $\alpha\alpha$ collisions, in particular, the step in energy which we have made is so large that we hope it may reveal some new phenomena, but in any case we think it should improve our understanding of old phenomena. This latter achievement has often been the neglected stepchild whenever the energy (or budget, etc.) was increased in searches for new phenomena.

Secondly: $\alpha$ particles are considered by heavy-ion physicists on the one hand as too-light nuclei. But particle physicists, on the other hand, consider them as too heavy, too complicated. Thus it only needs common sense to see that $\alpha$ particles must also have some advantages. I will skip the long list of advantages -- they are of both experimental and theoretical nature -- and only summarize them by saying that the $\alpha$ particle may establish a useful bridge between particle- and heavy-ion physics and between known phenomena and the dreamed-of new phenomena.

This contribution focuses on the production of particles in the central or pionization region in normal (soft) inelastic interactions. Knowing that central collisions are a favoured subject in these surroundings, it was tempting to select a topic which can be associated in one way or another with central collisions.

## 2. EXPERIMENT

The experiment was done using the Split Field Magnet Detector (SFMD). This is a large general-purpose device. It can detect charged particles and analyse their momenta over a solid angle close to $4\pi$. Figure 1 shows an artist's view of the apparatus. The two beam tubes can be seen as well as the lower iron yoke (the upper one has been "removed" by the artist). The magnet gap (field volume of 30 $m^3$ with an average field of

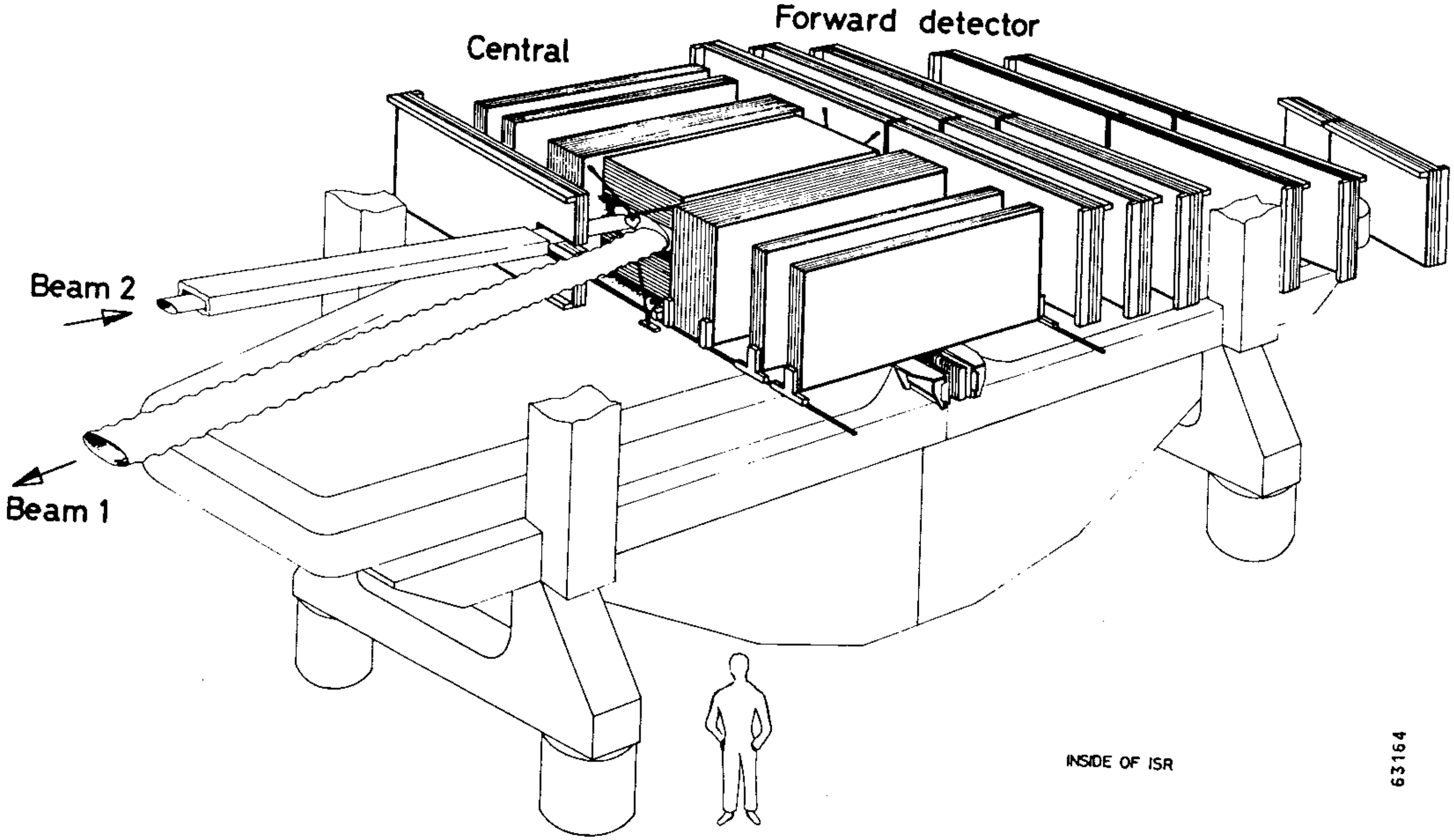

Fig. 1 Artist's view of the Split Field Magnet Detector

1 tesla) is filled with multiwire proportional chambers (MWPCs) with about 70,000 wires altogether. (Only some of the MWPCs are shown in the figure.)

In order to trigger this apparatus, combined wire signals are used -- signals of whole wire planes or of groups of neighbouring wires. To trigger on normal inelastic events ("minimum bias events"), only one track is required anywhere in the detector and one track is signalled by a coincidence of a reasonable sequence of at least five planes in any direction from the interaction vertex.

For the following results, events with at least one negative track were selected off line. Since fragmentation of nuclei without any particle production represents a good fraction [O(10%)] of inelastic $\alpha p$ and $\alpha\alpha$ interactions, this cut was considered to yield a cleaner sample of events with particle production. On the other hand, the minimum bias requirement is met, because the efficiency of detecting a negative track is higher than 90% and does not suppress or prefer any special topologies in y-space.

## 3. RESULTS

### 3.1 Particle densities in the central region

Figure 2 shows the ratio of particle densities at equal nucleon-nucleon c.m. energies ($\sqrt{s_{NN}}$ = 31 GeV) for $\alpha\alpha$ collisions to those for pp collisions, given separately for positive and negative tracks. These ratios have to be understood as qualitative, because the proton data were taken at a different magnetic field and at present there are uncertainties for the acceptance at this field value which can produce errors in the ratio of the order of 10-20%. But the following qualitative features can be seen.

The ratio is equal for positive and negative particles for c.m. rapidities ($y_{cm}$) around zero. This is consistent with the presence of a baryon-free central region and a rapidity gap of about 2 units between the two fragmentation regions. Towards the higher rapidities the negative ratio rises. Part of this rise can be explained by the different quark

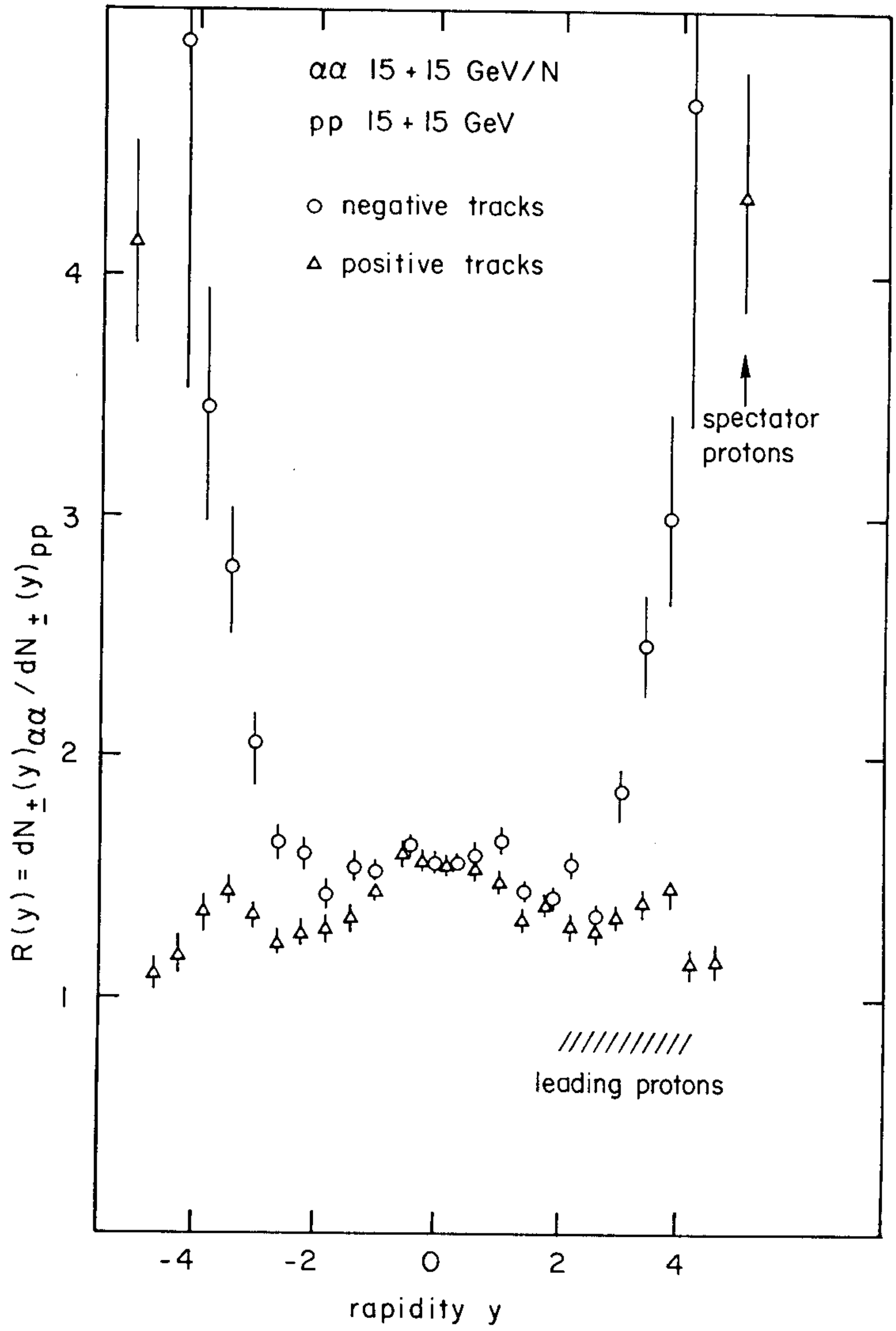

Fig. 2 Ratio of particle densities in αα collisions to pp collisions versus rapidity y

composition of α's and protons. The α's have equal numbers of up and down quarks, so one expects equal yields for $\pi^+$ and $\pi^-$ everywhere. Negative particles are dominantly pions. In pp interactions the $\pi^-/\pi^+$ ratio decreases to a value of ⅕ towards the edges of the rapidity space²⁾. So the increase of the negative ratio in Fig. 2 can be explained in part by the decrease of fast negative pions at high y in pp interactions. But part of the rise could be due to an enhanced pion production in the fragmentation regions of the nuclei³⁾. A more careful study of the particle densities in the fragmentation regions is needed to see whether this is the case.

The positive ratio, however, decreases at high rapidities. Again, this can be due to the different quark compositions. Half of the leading baryons in αα collisions are supposed to be neutrons -- which we do not see; in pp collisions they are mostly protons. Only at the highest y the positive ratio rises, owing to the spectator protons from the α particle. The two humps in the ratio of positive tracks are an artefact due to the assignment of a pion mass to all charged particles. Thus baryons get a higher rapidity (by $\ln [m_T(\text{baryon})/m_T(\text{pion})]$) than their true one.

Now let us focus on the central rapidities. If we compare the αα and αp data with pp data taken at 62 GeV c.m. energy, we have the same magnetic field and the same acceptance. We find a central ratio $R_c$ of 1.45 ± 0.05 for αα to pp and 1.07 ± 0.05 for αp to pp. Errors include statistical and systematical uncertainties; the latter were estimated by a comparison of the ratio at different azimuthal angles. The rise of the central particle density with energy has been measured for pp collisions in the ISR by two experiments⁴⁾. The increase is 20 ± 5% going from 31 to 62 GeV and 11 ± 5% from 44 to 62 GeV. Using these correction factors to obtain $R_c$ at equal c.m. energies (per nucleon-nucleon collision), we get

$$\begin{aligned} R_c\left(\frac{\alpha\alpha}{pp}\right)\Bigg|_{31\ \text{GeV}} &= 1.74 \pm 0.09 \\ R_c\left(\frac{\alpha p}{pp}\right)\Bigg|_{44\ \text{GeV}} &= 1.18 \pm 0.07\ . \end{aligned} \tag{1}$$

Why are the particle densities in the central (pionization) region interesting? Comparing particle densities in the central region for inelastic pp or $\pi p$ interactions with the ones for $e^+e^-$ annihilation or deep inelastic lepton scattering should tell us, at least qualitatively, which mechanism is at work in hadron-nucleon interactions, because we believe we understand fairly well the mechanism in $e^+e^-$ annihilation and lepton-nucleon scattering within the framework of QCD $^{5)}$.

Another approach to learn about this mechanism is to compare the central particle production in pp interactions with that in proton-nucleus and nucleus-nucleus interactions. Of course there is an additional challenge if one follows this approach. Once the mechanism in pp interactions is understood we can look for those phenomena which are bound to occur only in collisions of nuclei$^{3,6)}$.

We have some quantitative predictions for $R_c$. One was presented by Brodsky two years ago here at LBL $^{7)}$. In his model sea partons of the projectile and target interact by the exchange of gluons. The central particles are produced by the subsequent colour neutralization which takes place between the sea partons and the valence partons. His prediction for the central ratio $R_c$ can be entirely expressed in terms of production cross-sections:

$$
\begin{aligned}
R_c\left(\frac{\alpha\alpha}{pp}\right) &= \frac{2A\sigma_{\alpha p}}{\sigma_{\alpha\alpha}}\left[1 - (\tfrac{1}{2})^{A\sigma_{pp}/\sigma_{\alpha p}}\right] = 1.80 \pm 0.13 \\
R_c\left(\frac{\alpha p}{pp}\right) &= \frac{A\sigma_{pp}}{2\sigma_{\alpha p}} + 1 - (\tfrac{1}{2})^{A\sigma_{pp}/\sigma_{\alpha p}} = 1.16 \pm 0.07 \ .
\end{aligned}
\qquad (2)
$$

The errors result from the uncertainties of the measured$^{8)}$ production cross-sections.

In the model of Białas$^{9)}$, the central particle ratio is equal to the number of colour strings between wounded quarks and can be expressed in terms of quark cross-sections on nucleons and nuclei$^{10)}$

$$
R_c\left(\frac{\alpha\alpha}{pp}\right) = \frac{\sigma^2_{\alpha q}}{\sigma_{qq}\sigma_{\alpha\alpha}} = 1.77 \ , \qquad R_c\left(\frac{\alpha p}{pp}\right) = \frac{3\sigma_{\alpha q}}{\sigma_{\alpha p}} = 1.16 \ . \qquad (3)
$$

While for some other models$^{11)}$, the increase of the central particle density (1) is found to be surprisingly high, the agreement of the data with the predictions (2) and (3) is striking, but we find this agreement quite puzzling, because both models did not look so good when compared with data from another experiment, where we studied proton-nucleus collisions at energies between 20 and 150 GeV at the SPS $^{12)}$. Extrapolating from these data one would expect no change of the central particle density in $\alpha$p collisions as compared to pp collisions.

### 3.2 Two-particle correlations in the central region

One approach to learn more about the properties of the hadron matter created in the central region is to study particle correlations. We have started to study two-particle correlations and some examples for the normalized two-particle correlation function $R(y_1,y_2)$ will be shown. The latter is defined as

$$R(y_1,y_2) = \frac{\rho(y_1,y_2)}{\rho(y_1)\rho(y_2)} - 1 \ , \qquad (4)$$

with $\rho(y_1,y_2)$ being the inclusive two-particle density and $\rho(y_i)$ the inclusive single-particle density. Figure 3a shows $R(0,y_2)$ -- one particle was at $y_1 = 0 \pm 0.5$ -- for pp, $\alpha\alpha$, and $\alpha$p interactions. The correlation function has a characteristic triangular shape, and for pp interactions both the width and height agree well with previous measurements in the ISR $^{13)}$. For $\alpha\alpha$ interactions the width increases and a slight increase in the height can be observed. For $\alpha$p interactions the proton-side (negative $y_2$) follows closely the 31 GeV pp data, while the $\alpha$-side (positive $y_2$) follows the $\alpha$ data. This looks very systematic but what does it tell us? Indeed, not much yet because a large part of this correlation can be understood by the presence of at least two distinct components in the sample of inelastic events; the diffractive and the non-diffractive components, which have qualitatively different rapidity distributions. By selecting a particle with $y_1 \approx 0$ we very likely select a non-diffractive event, so the chance of finding another central particle is higher than for the average event.

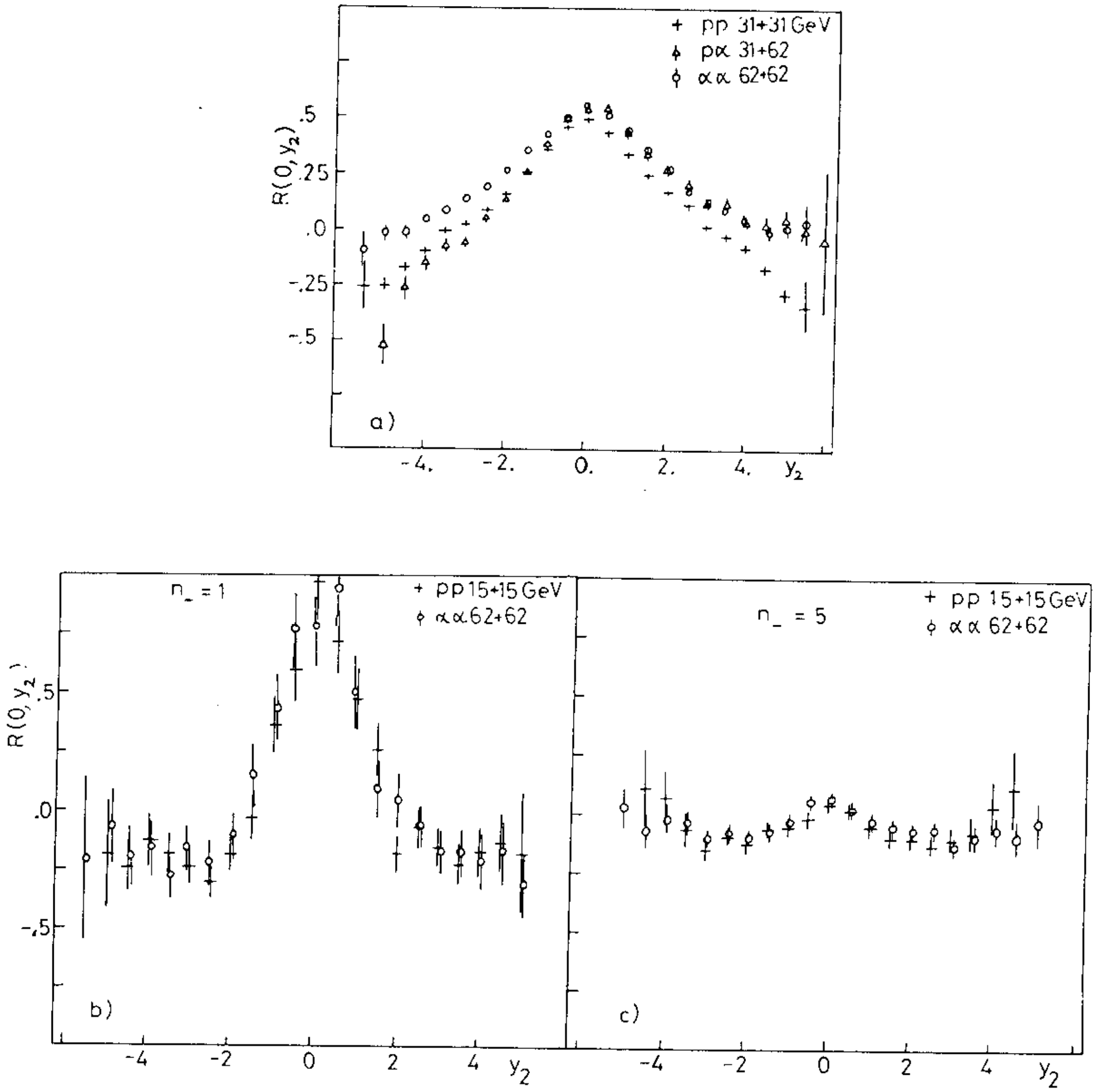

Fig. 3 Two-body correlation function [see Eq. (4)] for pp, αp, and αα inelastic interactions:

a) "minimum bias" events with at least one negative track;

b) fixed multiplicity: 1 negative track;

c) fixed multiplicity: 5 negative tracks.

A way to isolate true correlations from this sort of correlation is to study correlations at fixed multiplicity. Two examples are shown in Figs. 3b and c. In Fig. 3b events with a negative multiplicity of one (exactly 1 negative particle) were selected; for Fig. 3c the negative multiplicity was five. A much sharper peak can be seen now, indicating the presence of short-range correlations. The width of about 1 unit in $y_2$ is the correlation length. From an analysis of such correlations one may deduce the average multiplicity of a cluster decay in the framework of cluster production models[13]. We have not done this yet, but it is apparent that the differences between $\alpha\alpha$ and pp interactions are small. The observed decrease of the correlation in both cases with increasing multiplicity can be readily interpreted in cluster production models. Larger multiplicity implies a larger number of clusters. If the clusters are independent from each other, the average correlation between particles should increase with increasing cluster number.

## 4. SUMMARY

A significant rise of particle densities in the central region has been observed in $\alpha\alpha$ and $\alpha p$ interactions compared with pp interactions at the same c.m. energy per nucleon-nucleon collision. The pattern of two-particle correlations in the central region seems to be very similar for pp, $\alpha p$, and $\alpha\alpha$ interactions.

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