EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/84-125
17 September 1984

MESSAGE FROM LIGHT IONS: AN EXPERIMENTAL REVIEW OF THE
SEARCH FOR ABNORMAL PHENOMENA IN HIGH-ENERGY
NUCLEUS-NUCLEUS COLLISIONS

R. Szwed

Institute of Experimental Physics
University of Warsaw, Warsaw, Poland

ABSTRACT

The experimental data from the CERN Intersecting Storage Rings (ISR) and from Dubna and Berkeley on the search for abnormal nuclear phenomena in high-energy nucleus-nucleus collisions is reviewed.

Invited talk given at the
4th Int. Conf. on Ultra-Relativistic Nucleus-Nucleus Collisions:
Quark Matter '84
Helsinki, 17-21 June 1984.

1. INTRODUCTION

In a year and a half from now, the first experiments at the CERN Super Proton Synchrotron (SPS) using light ion beams (up to ^{16}O) should take place [1]. For the first time, both the powerful accelerator ($E > 10 \text{ GeV/n}$) [2] and the detectors will be used. Since the ion program at the SPS is not far ahead, there is much theoretical speculation about the possible observation of abnormal nuclear phenomena in ^{16}O interactions with nuclear targets [3,4].

The aim of the present paper is to present a brief review of the experimental results from the CERN Intersecting Storage Rings (ISR) and from Dubna and Berkeley in order to illustrate the present experimental status in the search for abnormal nuclear phenomena in the nucleus-nucleus collisions.

A straightforward extrapolation from the existing data to the interactions of ^{16}O with nuclear targets at the 200 GeV/n (maximum SPS energy) will be attempted. The weak points of the present experimental approaches to the search for abnormal nuclear phenomena will be pointed out.

The paper is organized as follows: In Section 2 the pion production is discussed and the experimental data on the temperature of produced pions are reviewed. In Section 3 the new experimental data on strangeness production from Dubna and the ISR are presented. The pion and baryon density as a function of the rapidity and multiplicity is discussed in Sections 4 and 5, respectively. Section 6 contains a brief comment on the study of the particle production with large transverse momenta in nucleus-nucleus collisions. In Section 7 some technical remarks on the central collision trigger are presented.

After each section there will be a summary, divided into three parts:

S (summary): A brief summary of the pure experimental facts reviewed in the section.

E (extrapolation): An extrapolation from the known experimental results to ^{16}O - ^{207}Pb collisions at 200 GeV/n.

D (drawbacks): The weak points of the experimental approach discussed in the section.

The conclusions are given in the last section.

2. PION PRODUCTION AND TEMPERATURE

2.1 PION YIELDS

Pions are the most frequently produced particles in high-energy collisions; therefore, knowledge of the pion production mechanism is essential for the understanding of the main features of high-energy nucleus-nucleus collisions.

The pion multiplicities from the collisions of various projectile nuclei A_P (d, α , ..., Ne) with various targets A_T (Li, ..., Pb) were measured at the Dubna energy [momentum: $p = 4.2$ (4.5) GeV/c per nucleon or kinetic energy: $E_K = 3.36$ (3.66) GeV per nucleon] by track detectors [5-8]. They were well reproduced by the models assuming independent multiple nucleon scattering [9]. The ISR $\alpha\alpha$ and αp study [10-12] led to similar conclusions. The models [13-16] assuming independent parton-parton collisions and using an eikonal approximation to calculate different multiple scattering terms, predict rather well the multiplicities and rapidity distributions observed in $\alpha\alpha$ ($\sqrt{s} = 30.4$ GeV/n corresponding to a laboratory momentum $p = 516$ GeV/c per nucleon) and αp ($\sqrt{s} = 44$ GeV/n corresponding to a laboratory momentum $p = 1031$ GeV/c per nucleon). The best agreement with the data is achieved within the dual-parton model [16,13]. For more information, the reader is referred to the existing reviews on the subject [17,18].

2.2 PION TEMPERATURES

The other characteristic of the production mechanism is the temperature of the pion source. A large increase in the temperature is necessary to pass from the normal hadronic phase to the quark-gluon phase [3,4]. Following the arguments of Hagedorn and Rafelski [19,20], it can be said that 'the temperature is most reliably measured through the measurement of the mean transverse momenta of the particles'. In fact, within a given thermodynamical model (see, for example, ref. [19]), the average transverse momentum of produced pions can be related to the temperature of the collision. Figure 1 shows a compilation of the experimental data from nucleon-nucleon [12,21,22] and nucleus-nucleus [6,8] collisions. The average transverse momenta of produced negative pions, $\langle p_T^\pi \rangle$, are plotted as a function of the initial projectile momentum. A strong increase of the average transverse momentum measured in nucleon-nucleon collisions is seen

in the range from 1 to 10 GeV/c (the energy threshold effects), whereas for the higher energies the rise is logarithmic, which is equivalent to the well-known fact of the limited transverse momenta of particles produced in the high energy hadron collisions. Owing to the rather drastic increase of $\langle p_T^\pi \rangle$ in the few-GeV energy range, more can be learnt about the production mechanism by studying the average p_T ($\equiv$ temperature) dependence on the energy and centrality. The centrality dependence of the $\langle p_T^\pi \rangle$ was extensively studied by the Dubna track detectors [6,8] by colliding many different pairs of nuclei and using different triggers, namely: 'minimum bias trigger' (all inelastic events); 'semi-central trigger' (charged forward-going fragments suppressed); 'central trigger' (charged and neutral forward-going fragments suppressed) [9]. As an example, some measurements are displayed in Fig. 1. No rise of the $\langle p_T^\pi \rangle$ with the increasing centrality and size of colliding nuclei is seen within the experimental errors, contrary to what is expected within the simple thermodynamical models. The quantitative agreement with the data is achieved within a multiple scattering model [23] which uses an extension of the Glauber model and the theoretical ideas coming from the particle-nucleus interactions. As seen in Fig. 1, the $\langle p_T^\pi \rangle$ measured for the different pairs of the colliding nuclei is slightly lower than that extrapolated from the nucleon-nucleon data.

At Berkeley, the slope factor E_0 , when inclusive cross-sections of the produced particles are parametrized by an exponential formula $\exp(-E_K^*/E_0)$ (E_K^* is a kinetic energy in the c.m. frame), is usually taken as a measure of the temperature. In Fig. 2 the energy dependence of the temperature of pions and protons at $\Theta_{cm} = 90^\circ$ is plotted for collisions of ^{20}Ne - ^{23}Na - ^{19}F at $E_K = 0.4, 0.8, \text{ and } 2.1$ GeV/n ($p = 0.95, 1.46, 2.89$ GeV/c per nucleon) [24]. The shape of the energy dependence of the temperature is quite similar to that from Fig. 1, but a direct comparison is impossible. Nevertheless, using the model [19], it is possible to relate T and $\langle p_T^\pi \rangle$, and the result obtained in such a way¹ is plotted in Fig. 1. The Berkeley data-points follow rather closely the energy dependence of $\langle p_T^\pi \rangle$ measured in the nucleon-nucleon interactions.

¹ The temperature values T evaluated from the $\langle p_T^\pi \rangle$ (or vice versa) are only approximately correct owing to the ambiguities in the calculation connected to the inclusion of pions from the Δ decays and other effects [19].

The temperatures and the average transverse momenta of negative hadrons were obtained for the $\alpha\alpha$, αp , and pp scatterings at the ISR energies [12] by the fitting procedure using Hagedorn's prescription [20]. The results are listed below and are plotted in Fig. 1:

	$\sqrt{s}$ [GeV]	$\langle p_T^{h^-} \rangle$ [MeV/c]	T [MeV]
$\alpha\alpha$:	31.2	363 ± 20	145 ± 8
αp :	44	357 ± 20	143 ± 8
pp :	30.4	364 ± 19	147 ± 7
pp :	44	366 ± 20	145 ± 7

As can be seen, the temperatures or average transverse momenta of the negative hadrons produced in $\alpha\alpha$ and αp collisions are similar to those measured in the pp collisions at the corresponding c.m. energies.

S: The multiplicity and rapidity results from nucleus-nucleus collisions at low ($p = 4.5$ GeV/c per nucleon) and high ($p = 516$ GeV/c per nucleon) energies, are in good agreement with predictions of the theoretical models, which assume additivity of the independent parton-parton (nucleon-nucleon) interactions.

No increase of the temperature ($\langle p_T^\pi \rangle$) is seen (within experimental errors) with increasing centrality and size of the colliding nuclei. The energy dependence of $\langle p_T^\pi \rangle$ is close to the one observed for nucleon-nucleon collisions.

E: The simple extrapolation from the existing data to the case of ^{16}O colliding with nuclear targets at 200 GeV/n gives the following temperature and average p_T of produced pions: $\langle p_T^\pi \rangle \approx 335$ MeV/c , $T \approx 140$ MeV.

D: There is no systematic study of the temperature of the produced pions using different colliding ion pairs and the central collision trigger at Berkeley energies.

3. STRANGENESS PRODUCTION AND TEMPERATURE

3.1 STRANGENESS YIELDS

There is a common belief that the abundant strangeness production will serve as evidence of the phase transition to the quark-gluon plasma.

Two experiments using the streamer chambers [25-27] and one using the bubble chamber [28] measured strange-particle yields by identifying the neutral strange decays (K_S^0 and Λ). At Berkeley the semi-central collisions of ^{40}Ar with $^{39}\text{K}^{33}\text{Cl}$ as a target were investigated [25], and the following value of the ratio of the average number of produced Λ 's, $\langle n^\Lambda \rangle$, to the average number of produced negative pions, $\langle n^\pi \rangle$, was found: $\langle n^\Lambda \rangle / \langle n^\pi \rangle = 0.04/6 \approx 0.7 \times 10^{-2}$. The topology for Λ -producing events was similar to that for the rest of the events. The Dubna experiments observe a strong increase of the strange particle yield when, say, the 'central' ^{16}O - ^{207}Pb interactions are compared with 'inelastic' ^4He - ^6Li , but a strong increase of the pion production is also observed and the relative ratio stays constant, as one can see in Fig. 3 [27]. The amount of produced K_S^0 's and Λ 's is proportional to the number of nucleons participating in the collision [27]. Taking into account a rather large energy difference (threshold effects) between the Berkeley and Dubna experiments, the $\langle n^\Lambda \rangle / \langle n_- \rangle$ ratios measured at Dubna and Berkeley are astoundingly close.

The only available information at higher energies comes from the R807 experiment at the CERN ISR [29]. The multiplicity dependence of the ratio of strange charged kaons to the charged pions is presented in Fig. 4 for $\alpha\alpha$, αp , and pp collisions at the corresponding c.m. energies. The ratio does not depend on the multiplicity (centrality).

3.2 TEMPERATURE

A compilation of the Λ 's average transverse momenta measured in high-energy nucleus-nucleus collisions is presented in Fig. 5. The data come from two Dubna experiments performed at $p = 4.2$ GeV/c per nucleon [28] and $p = 4.5$ GeV/c per nucleon [26,27], and the Berkeley experiment²

² The error on the $\langle p_T^\pi \rangle$ was not given in the original publication, but must be slightly larger than the one of the Dubna data because of smaller statistics.

at $p = 2.89$ GeV/c per nucleon [25]. In order to obtain statistics, some data are summed, as indicated in Fig. 5. It is worth noting that the inelastic ${}^4\text{He}-{}^6\text{Li}$ interactions can be treated, to a first approximation, as the ideal average nucleon-nucleon collisions, owing to the smallness of the colliding objects and inclusion of the averaging over the Fermi momentum. No significant dependence of $\langle p_T^\pi \rangle$ on the size of the colliding nuclei and centrality is seen; nevertheless, the $\langle p_T^\Lambda \rangle$ for He-Li inelastic collisions is the smallest.

In Fig. 6 the compilation of the proton-proton [30] and nucleus-nucleus [25,27,28] data on the K_S^0 and Λ average transverse momenta is shown in a way that is similar to that for the pions in Fig. 1. The solid line recalls the behaviour of the π data. It can be seen from Fig. 6 that the $\langle p_T \rangle$ of K_S^0 's are smaller than those for Λ 's. The energy dependence of $\langle p_T^{K_S^0, \Lambda} \rangle_{pp}$ seems to be the same as for $\langle p_T^\pi \rangle_{pp}$. Unfortunately, all the nuclear collision data have very large experimental errors, so no final conclusions are possible. Still, the $\langle p_T^\Lambda \rangle$ for the centrally colliding symmetric nuclei (${}^{12}\text{C}-{}^{12}\text{C}$, ${}^{12}\text{C}-{}^{20}\text{Ne}$, and ${}^{16}\text{O}-{}^{20}\text{Ne}$) is noticeably larger. This particular sample was investigated in more detail by the streamer chamber group [31], and the following very promising observations were made. In a certain fraction of the investigated sample, the Λ 's were produced outside the kinematical limits. The authors called this sub-sample ' Λ^{out} '. Whereas the temperature of produced Λ 's in the inelastic He-Li ('average nucleon-nucleon' collisions) is around 107 ± 20 MeV, for the ' Λ^{out} ' sample it was 150 ± 19 MeV. Also, the pion temperature was much larger for those events, $T^\pi(\Lambda^{\text{out}}) = 114 \pm 11$ MeV, whereas for all other central or non-central collisions it was around 95 ± 5 MeV. Moreover, pions were produced isotropically in the nucleon-nucleon c.m. frame (flat distribution in $\cos\Theta^*$) in the ' Λ^{out} ' sample, whilst for the other samples they were forward-backward peaked. The selection of the ' Λ^{out} ' sample corresponds to a cross-section $\sigma = 10^{-3} \times \sigma_{\text{inel}}$, therefore the phenomenon could not be observed in the inclusive measurements. Assuming that the data are not affected by statistical fluctuations, these observations can be interpreted as evidence that the Λ 's and π 's are emitted from a single hot source, perhaps already from the other phase.

S: There is no evidence of copious strange-particle production in high-energy nucleus-nucleus interactions; no dependence on centrality and size of colliding nuclei is observed. The temperatures of strange particles produced in central nucleus-nucleus collisions are higher than the ones observed in the average nucleon-nucleon collisions.

The recent Dubna streamer chamber observation [31] shows that in the selected sub-sample of central collision events of symmetric nuclei, the Λ 's and π 's are produced from a single hot spot.

E: The extrapolation from existing data gives the following predictions for T^Λ and $\langle p_T^\Lambda \rangle$ to be observed in the central collision events at 200 GeV/c per nucleon: $T^\Lambda \approx 150$ MeV and $\langle p_T^\Lambda \rangle \approx 600$ MeV/c. If collisions of the symmetric nuclei (^{16}O - ^{16}O) were much better sources of the 'hot' Λ 's, the largest experimental problem -- how to deal with high multiplicity -- will be less serious at the SPS experiments.

D: The main drawback of the experimental study discussed in this section is the very low statistics. The small statistics is a result of the fact that no dedicated experiment measuring only strange particles has yet been done.

4. PION DENSITIES

Most of the predicted exotic phenomena in the high-energy nuclear collisions are strictly correlated with the high densities of the hadronic matter. At the energy $E_K = 3.66$ GeV ($p = 4.5$ GeV/c per nucleon) the average multiplicity of pions produced in nucleon-nucleon collisions is $\langle n^\pi \rangle < 1$, whereas at $p = 200$ GeV/c, $\langle n^\pi \rangle \approx 8.5$, so the situation is completely different in these two energy regions. At the SPS energies the pions will contribute to the bulk of the particle density.

The $\alpha\alpha$ experiment at the ISR gives information about the pion densities at even higher energies [32]. Figure 7 gives the multiplicity dependence of semi-inclusive rapidity distributions, for secondaries emitted into different rapidity regions in the $\alpha\alpha$ and pp collisions [12]. In the central rapidity region (Fig. 7a,d) we observe a linear growth of the rapidity density with multiplicity for both negative and positive secondaries. It is interesting to note that $\alpha\alpha$ data obey the same linear relation as that obeyed by the pp data, but obviously extended to much larger multiplicities. In the intermediate region of rapidity $2 < y < 3$ (Fig. 7b) the particle density in $\alpha\alpha$ and pp collisions still increases approximately linearly with the multiplicity. The growth is faster in the case of the $\alpha\alpha$ scattering than in the pp case. The same effect is more clearly manifested for the fragmentation region $4 < y < 6$ (Fig. 7c), where almost no increase of the particle density is seen in the pp case. Comparing the particle densities per rapidity unit in the average case [12,18] and for the

largest multiplicity sample in the central rapidity region (Fig. 7a), it can be seen that the particle density increases by a factor of ≈ 5 . Adding up positive and negative secondaries in Fig. 7 at $n_{ch} = 50$, we obtain $dn/dy \approx 15$ charged particles produced per rapidity unit. On top of this, fluctuations of the particle densities in an individual event can occur. Figure 8 shows such a fluctuation. The event was chosen out of 30,000 events as one of a few largest multiplicity events. In this particular event, 26 particles produced in one rapidity unit are seen. So the particle density can be quite large within one event because of the possible event-by-event fluctuations.

S: The highest pion densities are obtained for highest-multiplicity events and in the central rapidity region. This suggests that the central rapidity region may well be the most promising, when looking for exotic phenomena connected with the high local energy or hadron density.

E: Although it is rather difficult to make any predictions about the pion densities for the ^{16}O - ^{207}Pb collisions by extrapolating from the $\alpha\alpha$ data, some indirect ways do exist. The multichain dual-parton model introduced by the Orsay group [33] has been able to describe the multiparticle production in hadron-nucleus and recent $\alpha\alpha$ data with considerable success [16], as was discussed in Section 2.1. Therefore, it is relatively safe to use this model to predict pion densities at the new SPS experiments. The model predicts that even collisions of oxygen with heavy targets will produce an energy deposition slightly smaller than $1.5 \text{ GeV}/\text{fm}^3$ [34], the magic number believed to be a threshold density between the hadronic and the quark-gluon phase. The only hope, as the authors claim [34], is in the selection of very central events, by increasing the veto angle for the forward going projectile fragments.

D: Within the present experimental configuration it was impossible to set up the central collision trigger at the ISR. The subject will be discussed in more detail in Section 7.

5. BARYON DENSITIES

The baryon density achievable in central collisions of heavy nuclei at high energies is a topic of current interest. The reason is twofold: firstly, the baryon density can contribute, for a large part, to the total hadron density when two large nuclei collide; secondly, the only way the baryons are stopped is via emission of pions and other particles. Therefore, the stopping of nucleons is an equivalence of the abundant particle production. The stopping power or nuclear transparency is really a very important problem, because it is the 'to be or not to be' of high nuclear densities and all subsequent effects [35]. Recently, Busza and Goldhaber have interpreted hadron-nucleus data claiming stopping of the protons traversing the lead nucleus [36]. There is also evidence for isotropic flow of the energy and particles in ^{93}Nb - ^{93}Nb high-multiplicity collisions at 0.4 GeV/n kinetic energy [37]. However, the incident energy is very small and the cascade development is well justified even in the forward region [35], which is certainly not the case at 200 GeV/n energy.

Therefore it is interesting to look for the baryon densities in the high-energy nucleus-nucleus collision. The only candidate is again the $\alpha\alpha$ ISR data. Unfortunately, as a rule in the high-energy experiments, there is no particle identification in the full phase space, so even the proton rapidity distributions cannot be extracted from the data in a direct way. But, in the case of isoscalar beam and target collisions ($\alpha\alpha$ or dd scattering), fortunately it is possible to extract the proton rapidity spectra by playing a trick [12,32], which is the following: for both negative and positive secondaries the proton mass is assigned. Since the rapidity spectra for negative and positive pions are the same -- as there is the same amount of u and d quarks in the initial state -- their contributions cancel out in the difference. The influence on the result of the difference in positive and negative K production and of heavier fragments (registered with very small efficiency) is neglected. The result of such a procedure is shown in Fig. 9 for three different multiplicity bins. In the smallest-multiplicity bin (most peripheral collisions) it can be seen that the proton rapidity distribution is peaked at 3.5, exactly coinciding with the beam rapidity, and that it falls rapidly when the central rapidity region is approached. Large errors at central rapidity are the result of subtracting two large numbers. The mid-rapidity gap is clearly visible. When more central events (larger-multiplicity bin) are selected, a shift of the proton peak towards the central rapidity region is seen. We can assume that the neutron density is the same as the proton one in the $\alpha\alpha$ collision.

Therefore we can risk claiming that baryons can be stopped by nuclear matter when two large nuclei collide.

However, a warning seems to be necessary. At least part of the effect can be understood within a very simple phenomenological picture, namely: in the $\alpha\alpha$ collision with a large centrality, many nucleons have to interact with large inelasticity, so on the average the particle production is enhanced. Thus triggering on the high multiplicity, events can be selected, in which nucleons have undergone collisions with a large inelasticity and therefore have shifted towards the smaller rapidities. The disentangling of how much of the stopping of the nucleons is due to the secondary nucleon-nucleon collisions is the real non-trivial point. A comparison of the $\alpha\alpha$ and dd data can possibly shed light on the problem, and such a study will be undertaken by the R418 ISR Collaboration using existing experimental data.

S: The $\alpha\alpha$ data demonstrate that baryons can be slowed down by nuclear matter.

E: The baryon mid-rapidity gap can presumably be filled up, at least partially, in the oxygen collisions with large centrality, even at 200 GeV/n.

D: The real central collision trigger was not used in the ISR $\alpha\alpha$ experiments.

6. PARTICLE PRODUCTION WITH LARGE TRANSVERSE MOMENTA

At this conference there are a few papers [38] on particle production with large transverse momenta (or energy flow), presenting new interesting results from the $\alpha\alpha$ study at the ISR [39,40]. Therefore, this section will be limited to just a short remark.

Figure 10 brings to mind the well-known results obtained at the ISR, demonstrating 'Abnormal Nuclear Enhancement' (ANE) (discovered previously at Fermilab [41]) observed in the $\alpha\alpha$ collisions [42,17]. The lines plotted in Fig. 10 correspond to the theoretical predictions based on the multiple parton scattering mechanism [43-45]. As can be seen in this figure, only the model assuming multiple scattering and large Fermi momenta [44] gives satisfactory agreement with the data. The large Fermi momenta ($p_F > 500$ MeV) may appear from a non-trivial source. In fact, usually decays of the N^* or Δ resonances, or the existence of such exotic objects as multiquark states, enhance the large Fermi momentum tail [46].

It may well be that the study of the particle production with large transverse momenta is the best tool for searching for new physics phenomena in nucleus-nucleus collisions at high energies [35].

S: The ANE was observed in the h-nucleus and in the $\alpha\alpha$ interactions.

E: The cross-section for the particle production with large p_T will be amplified in the case of oxygen collisions, hence it grows with A_P and A_T at least as:

$$\sigma_{A_P A_T} / \sigma_{nn} \approx A_P \times A_T = 16 \times 207 = 3312.$$

Presumably $\sigma_{A_P A_T}$ will be much higher because of the ANE, but this is still to be measured. Much better experimental conditions for tagging projectile fragments exist at fixed-target experiments.

D: In spite of the fact that the ANE was observed for both the h-nucleus and the $\alpha\alpha$ experiments, no single experiment using heavier colliding nuclei was done at Berkeley or Dubna.

7. CENTRAL COLLISION TRIGGER

It is fairly clear that the highest hadron densities are achieved in events with the highest centrality. So events in which as many nucleons as possible deposit as much energy as possible should be selected. The way to do this is by using a high-resolution forward hadron calorimeter and, eventually, a tracking device for charged fragments as the main components of the central collision trigger.

The typical experimental configuration (fixed-target experiment) is shown in Fig. 11. The ^4He beam was chosen to simplify the picture. The projectile nucleus fragments in a target, and the nuclear fragments (except neutrons) are bent differently because of the different rigidities. The circles plotted in the plane placed perpendicularly to the beam direction 5 m away from a target, correspond to the transverse Fermi momentum of 100 MeV/c in the ^4He rest system. The detector is placed in a typical 1.5 T magnetic field. The distance d between centres of the outgoing neutrons and protons will change drastically with the incoming beam momentum, as indicated in Fig. 11. This sets rather serious constraints on the calorimeter device.

Whilst a central collision trigger is rather easy to build at fixed-target experiments, it is still only 'half a central trigger', because the information

about the target nucleus is lost. At the colliders the geometry of the colliding nuclei is symmetric, therefore a central collision trigger can be applied by vetoing nuclear fragments of both colliding nuclei. Unfortunately, it was impossible to apply such a trigger at the ISR, because it requires a special intersection region, described below. An attempt to veto the events with fast nuclear fragments registered at the forward regions of the detector, led to the selection of peripheral events with fragments lost in the beam tube.

At the moment, the construction of a few heavy-ion colliders is proposed [47]. The new colliders should have very special intersection regions (at least some of them) suitable for a heavy-ion study. A simplified sketch of the intersection layout is presented in Fig. 12. The outgoing vacuum pipes should have a sharp perpendicular wall at the edge to minimize the amount of the material to be traversed by the nuclear fragments. The prolongation of the vacuum tube should have a diameter as small as possible (limited only by current acceleration technology). All stripped nucleons, even those having very small perpendicular Fermi momentum, should traverse the wall and be registered in the calorimeter device surrounding the beam pipe in order to tag nuclear fragments.

Figure 9, which demonstrates the stopping power in the $\alpha\alpha$ collisions, also shows that even for the largest multiplicity bin the protons are peaked at the beam rapidity. This shows that the off-line multiplicity cut is only a poor-man's central collision trigger, and the chance to investigate the real central $\alpha\alpha$ collisions at the ISR is lost for ever.

D: No real central collision trigger (dedicated calorimeter device) was used up to now in the nucleus-nucleus study³ at any energy.

³ The only device that I am aware of was the 'neutron veto counter' used by the streamer chamber group at Dubna [48]. Unfortunately, it did not have any granularity or energy measurement capability.

8. CONCLUSIONS

Even the present brief review shows that a lot of study has been done experimentally in the field of the high-energy nucleus-nucleus collisions, and a great deal of the phenomena occurring when two nuclei collide are now understood. So far, no evident features or signals of the phase transition have been observed.

But a lot of experimental information is still missing. The best examples of the 'should be done' experiments in the few-GeV energy range are perhaps: a high statistics (preferably electronic) experiment measuring, in an exclusive way, strange particle production; and a similar experiment measuring particle production with large transverse momenta -- both using a real central collision trigger.

As far as high energies are concerned, we will have to wait until the appropriate beams are available. When preparing the ion adventure at the SPS we shall keep in mind that the ISR missed the charm and beauty not because of the lack of energy or proper beams but rather because of the lack of proper equipment at the right time.

Acknowledgements

I would like to thank all my colleagues in the ISR $\alpha\alpha$ adventure -- in particular M.A. Faessler, H.G. Fischer, S. Frankel, W. Geist, and I. Otterlund -- for enlightening discussions and close collaboration.

It gives me a great pleasure to express my appreciation to H. Białkowska, M. Gaździcki, E. Skrzypczak, A. Sandoval and R. Stock, who provided me with much of the indispensable information on the current high-energy nucleus-nucleus experiments.

The many discussions with B. Badełek, A. Capella, W.Q. Chao, L. Leśniak, H.J. Pirner, G. Wilk, and specially with R. Hagedorn on the theoretical aspects of the high-energy nucleus-nucleus collisions, are acknowledged with gratitude.

I would also like to thank the Dubna SKM-200 Collaboration and the CERN ISR R807 and R418 Collaborations for providing me with their unpublished results.

The comments of M.A. Faessler, K. Rybicki, and J. Zakrzewski and their careful reading of this manuscript were of very great help.

References

- [1] R. Stock, 'Quark matter searches using ^{16}O beams at the CERN SPS', talk given at this conference.
- [2] H. Haseroth, report CERN/PS/LI/82-12 (1982), and in Proc. Workshop on SPS Fixed-Target Physics in the Years 1984-1989, Geneva, 1982 (CERN 83-02, Geneva, 1983), Vol.II, p. 443.
- [3] See articles by J. Rafelski, H. Satz, J. Kapusta and L. McLerran, in Phys. Rep. 88 (1982) 321.
- [4] M. Jacob, CERN report Ref.TH.3728 (1983), and in Proc. Third Int. Conf. on Ultra-Relativistic Nucleus-Nucleus Collisions (Quark Matter '83), BNL, Upton, 1983 (Nord Holland, Amsterdam, 1984), p. 7c.
- [5] V.D. Aksinenko et al., Nucl. Phys. A324 (1979) 266.
V.D. Aksinenko et al., Nucl. Phys. A348 (1980) 518.
M.Kh. Anikina et al., Z. Phys. C9 (1981) 105.
- [6] A.Kh. Abdurakhimov et al., Nucl. Phys. A362 (1981) 376.
- [7] E.A. Abdrakhmanov et al., Z. Phys. C5 (1980) 1.
H.N. Agakishev et al., Z. Phys. C16 (1983) 307.
- [8] H.H. Agakishev et al., Z. Phys. C12 (1982) 283.
- [9] R. Szwed, Warsaw Univ. report IFD/2/81 (1981), and in Proc. 5th High Energy Heavy Ion Study, Berkeley, 1981 (LBL-12652, Berkeley, 1981), p. 371.
- [10] T. Åkesson et al., Phys. Lett. 119B (1982) 464.
- [11] W. Bell et al., Phys. Lett. 128B (1983) 349.
- [12] W. Bell et al., 'Charged particle spectra in $\alpha\alpha$ and αp collisions at the CERN ISR', CERN ISR R418 experiment, paper in preparation.
- [13] W.Q. Chao and H.J. Pirner, Z. Phys. C14 (1982) 165.
- [14] S.J. Brodsky et al., Phys. Rev. Lett. 39 (1977) 1120.
- [15] A. Białas et al., Z. Phys. C13 (1982) 147.
L. Leśniak, private communications.
- [16] A. Capella et al., Phys. Lett. 108B (1982) 347.
A. Capella, private communication.
- [17] M.A. Faessler, 'Experiments with alpha particles at the CERN Intersecting Storage Rings', preprint CERN-EP/84-64 (1984), to be published in Phys. Reports.
- [18] R. Szwed, in Proc. Int. Conf. on High Energy Nuclear Physics, Balatonfüred, 1983 (KFKI, Budapest, 1983), p. 197.
- [19] R. Hagedorn and J. Rafelski, Phys. Lett. 97B (1980) 136.
- [20] R. Hagedorn, CERN preprint Ref.TH.3684 (1983).
- [21] A. Abdivaliev et al., JINR report BI-1-122181 (1979).

- [22] A.M. Rossi et al., Nucl. Phys. B84 (1975) 269.
H. Boggild et al., Nucl. Phys. B57 (1973) 77.
J.W. Chapman et al., Phys. Lett. 47B (1973) 465.
T. Kafka et al., Phys. Rev. D16 (1977) 1261.
- [23] C. Pajeras and A.V. Ramallo, Phys. Lett. 120B (1983) 441.
- [24] S. Nagamiya et al., Phys. Rev. C24 (1981) 971.
- [25] J.W. Harris et al., Phys. Rev. Lett. 47 (1981) 229.
- [26] M. Anikina et al., Phys. Rev. Lett. 50 (1983) 1971.
M. Anikina et al., in Proc. Int. Conf. on High Energy Nuclear Physics, Balatonfüred, 1983 (KFKI, Budapest, 1983), p. 433.
- [27] M. Anikina et al., 'Characteristics of Λ and K_S^0 particles produced in central nucleus-nucleus collisions at a 4.5 GeV/c momentum per incident nucleon', to be published in Z. Phys. C.
- [28] N. Akhababian et al., JINR report D1-82-455 (1982).
S. Arakelian et al., JINR report P1-83-354 (1983).
- [29] S. Frankel, private communication, CERN ISR R807 experiment, paper in preparation.
- [30] K. Jaeger et al., Phys. Rev. D11 (1975) 1756.
P. Aahlin et al., Phys. Scripta 21 (1980) 12.
H. Boggild et al., Nucl. Phys. B57 (1973) 77.
V.V. Ammosov et al., Nucl. Phys. B115 (1976) 269.
J.W. Chapman et al., Phys. Lett. 47B (1973) 465.
K. Jeager et al., Phys. Rev. D11 (1975) 2405.
F. LoPinto et al., Phys. Rev. D22 (1980) 573.
A. Sheng et al., Phys. Rev. D11 (1975) 1733.
- [31] M. Anikina et al., JINR report E1-84-376 (1984).
- [32] R. Szwed, 'Charged particle production in $\alpha\alpha$, αp , dd , and pp collisions at the CERN ISR', ISR R418 and R419 experiments, talk given at the XVth Symp. on Multiparticle Dynamics, Lund, 1984.
- [33] J. Tran Thanh Van, 'New results on the dual parton model', talk given at the XVth Symp. on Multiparticle Dynamics, Lund, 1984.
- [34] A. Capella et al., CERN preprint Ref.TH.3700 (1983).
- [35] R. Szwed, report CERN-EP/83-50 (1983) and in Proc. Int. Workshop on Gross Properties of Nuclei and Nuclear Excitations XI, Hirschegg, 1983 (GSI, Darmstadt, 1983), p. 119.
- [36] W. Busza and A.S. Goldhaber, Phys. Lett. 139B (1984) 235.
- [37] H.H. Gutbrod et al., in Proc. Int. Conf. on High Energy Nuclear Physics, Balatonfüred, 1983 (KFKI, Budapest, 1983), p. 269.
H. Pugh, 'Equilibration, compression and flow at the Bevalac', talk given at this conference.

- [38] See talks given by B. Callen ('Measurement of E_T flow for pp, dd and $\alpha\alpha$ interactions') and M. Tannenbaum (' E_T and π^0 spectra from $\alpha\alpha$, dd, pp at $\sqrt{s} = 31$ GeV') at this conference.
- [39] A.L.S. Angelis et al., Phys. Lett. 141B (1984) 140.
- [40] A. Breakstone et al., 'Composition of Particles Emitted at Large p_T and Medium Angles in pp, dd, and $\alpha\alpha$ Collisions at the ISR', CERN ISR R418 and R419 experiments, paper in preparation.
- [41] J.W. Cronin et al., Phys. Rev. D11 (1975) 3105.
L. Kluberg et al., Phys. Rev. Lett. 38 (1977) 670.
- [42] A. Karabarbounis et al., Phys. Lett. 104B (1981) 75.
W. Bell et al., Phys. Lett. 112B (1982) 271.
A.L.S. Angelis et al., Phys. Lett. 116B (1982) 379.
T. Åkesson et al., Nucl. Phys. B209 (1982) 309.
- [43] U.P. Sukhatme and G.Wilk, Phys. Rev. D25 (1982) 1978.
- [44] M. Staszal and G. Wilk, Z. Phys. C19 (1983) 57.
- [45] M. Lev and B. Petersson, Z. Phys. C21 (1983) 155.
- [46] H.J. Weber, Phys. Lett. 80B (1978) 232.
G. Horlacher and H. Arenhovel, Nucl. Phys. A300 (1978) 348.
- [47] See talks given by T. Ludlam ('Heavy ion collider') and H. Pugh ('New scheme for a heavy ion collider at LBL') at this conference.
- [48] M. Gaździcki et al., JINR report E1-84-444 (1984).

Figure captions

- Fig. 1: Compilation of the data on the dependence of the average transverse momenta of negative pions produced in nucleon-nucleon [12,21,22] and nucleus-nucleus [6,8] interactions on the incoming beam momentum. The solid line is plotted to guide the eye.
- Fig. 2: The energy dependence of the slope factor E_0 , fitted to the proton and pion spectra at $\Theta_{cm} = 90^\circ$, in Ne-NaF collisions [24]. The cross-sections were parametrized by $\exp(-E_K^*/E_0)$, where E_K^* is the kinetic energy in the c.m. frame.
- Fig. 3: Ratios of the average number of K_S^0 's (top figure) and Λ 's (bottom figure) to the average number of negative secondaries produced in the nucleus-nucleus collisions [26-28]. In order to gain statistics, some data having close values of the product $A_P \times A_T$ (the projectile and target mass numbers, respectively), were added up and are represented by a single data point.
- Fig. 4: The dependence of the ratio of charged kaons to the charged pions measured for the $\alpha\alpha$, αp , and pp interactions by the ISR R807 experiment [29] on the charged multiplicity m ; $\langle m \rangle$ denotes the mean charged multiplicity.
- Fig. 5: Average transverse momentum of Λ 's produced in nucleus-nucleus collisions [25,27,28] versus the mass number product of the colliding nuclei.
- Fig. 6: Compilation of the data on the dependence of the average transverse momenta of the K_S^0 's and Λ 's produced in the proton-proton [30] and nucleus-nucleus collisions [25,27,28] on the incoming beam momentum. The solid line corresponds to the pion data presented in the Fig. 1.
- Fig. 7: Multiplicity dependence of rapidity density for three different rapidity regions: a) $|y| < 1$; b) $2 < |y| < 3$; c) $4 < |y| < 6$; in $\alpha\alpha$ and pp interactions [12].
- Fig. 8: 'Spike' rapidity event registered in $\alpha\alpha$ interactions [32].
- Fig. 9: Net proton rapidity distributions for $\alpha\alpha$ collisions for three different multiplicity bins [32].
- Fig. 10: Ratio of the negative hadron and π^0 yields as a function of p_T . Compilation of the ISR $\alpha\alpha$ data [42]. The curves represent predictions of the multiple-parton scattering models [43-45].

- Fig. 11: Schematic representation of the triggering on central collisions at a fixed-target nucleus-nucleus experiment. For more explanation, see text.
- Fig. 12: Schematic representation of the triggering on central collisions in a collider nucleus-nucleus experiment.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12