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HADRONIC OBSERVABLES AT NA49[1]

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A variety of preliminary results from the NA49 experiment, illustrating its capabilities for extracting physics from 158 GeV per nucleon b+Pb collisions are presented and discussed in terms of what they may imply about the dynamics of the created source and future directions of analysis.

1. Introduction

The goal of Ultra-Relativistic Heavy Ion Experiments is the observation and characterization of the phase transition of normal nuclear matter into the color conducting deconfined state known as the Quark-Gluon Plasma (QGP). Many possible signatures have been suggested[1], but as more and more experimental data become available it is becoming clear that such a phase transition will not manifest itself through a single "smoking-gun" observable, or even experiment—at least not if one presupposes its existence in the current regime of CERN-SPS and BNL-AGS experiments. Rather convincing evidence for the formation and existence of the QGP will come from measurements over a wide range of physics observables that, considered together, cannot be explained by conventional means.

In this vein the best strategy is to measure as many different observables as possible and search for correlations between them in order to localize or select an interesting sub-sample of events in which extraordinary physics may be occurring. For example, if a certain class of events had a higher than average p_T, along with an anomalously high multiplicity and K/π ratio, it would be an indication that perhaps something unusual may have occurred.

To some extent this philosophy speaks toward the main goal of NA49— that is Event-by-Event physics where fluctuations in observables are searched for at the event level in order to select interesting or anomalous candidate events, as outlined by Stock.[2] However this is not a stand-alone program as one must define fluctuations from a specific reference and characterize what the expected average properties of a generic event really are. With this motivation it is worthwhile to look at the characteristics of some of the observables, NA49 measures, both at the ensemble level and the event level.

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2. The Experiment

NA35 was the first experiment to attempt to measure the remnants of a relativistic heavy ion collision over a large region of phase space. It was sensitive to final state charged hadrons and neutral strangeness through the kinematical reconstruction of charged decay products, in a large volume streamer chamber. The streamer chamber was located in a strong (1T) dipole magnetic field such that momentum reconstruction could be carried out. A Ring-Imaging Cerenkov (RICH) was also used in order to facilitate Particle Identification (PID) over a restricted region of phase space. NA35 also had extensive calorimetry in order to measure transverse energy production as well as forward energy. The complete experimental apparatus is described in detail elsewhere.[3] A small Time-Projection-Chamber (TPC) was added to augment the particle tracking capabilities at near beam rapidity. This also provided evidence that a TPC could function in heavy ion experiments at CERN-SPS energies. This led to the design of NA49 which continues the same type of research program into the CERN-SPS Pb era.

NA49 shares the same philosophy of design with NA35—that is, large acceptance phase space coverage of final state charged hadrons with PID capabilities—but with four large volume TPCs to facilitate tracking and PID.[3] Time-of-Flight (TOF) arrays augment the PID capabilities of the spectrometer and the calorimetry from NA35 is also retained to complete the experimental setup. The TPCs were necessary since even in the 200 GeV A S-S collisions, the optical imaging techniques utilized for particle tracking, like the streamer chamber were at their limits and it was not feasible to apply them in the higher multiplicity environment of Pb-Pb interactions. environment. The TPCs provided not only an increase in spatial and momentum resolution for tracking, but also allowed for an increase in the size of data set by the electronic nature of the detector.

3. Event Characterization

Lattice QCD calculations[4] have given predictions regarding the conditions necessary for the formation of the deconfined QGP. These conditions are roughly as follows:

- High temperature (T$\sim$ 140-200 MeV).
- High density ($\rho \sim$ 5-10ρ_o).
- High Energy density ($\epsilon \sim$ 1-10 GeV fm^{-3}).

At the so-called Hagedorn temperature (T $\sim$ 165 MeV), lattice calculations predict a large increase in the number of available degrees of freedom, which is interpreted as the deconfinement of quarks and gluons from their parent hadrons. The question relativistic heavy ion experiments address are two-fold. First they must establish that conditions necessary for plasma formation do exist in collisions, and second, from the measurement of final state products, deduce that the new phase did transiently exist. Since this phase transition is not an observable, this program reduces to carrying out model studies, which requires a thorough understanding of the systematics of the observables. In the quest of such goals, both NA35 and NA49 look at the charged (and neutral strange) hadrons in the final states.

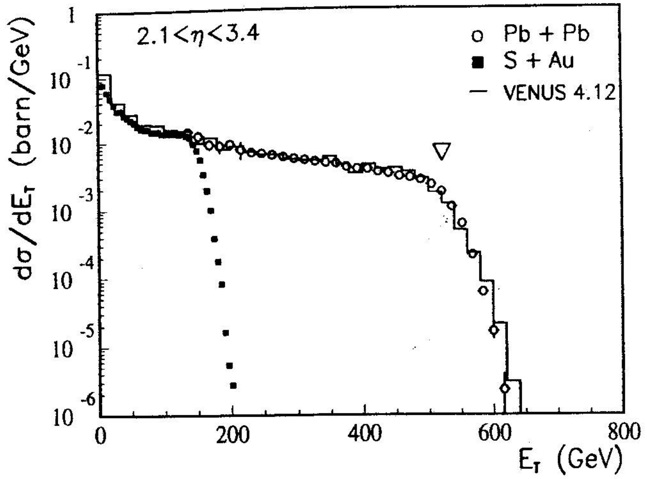

Fig. 1. Comparison between NA35 S-S, NA49 Pb-Pb, and a model calculation for transverse energy production over a limited region of pseudo-rapidity. The highest multiplicity is seen in events with the highest E$_T$. Monte Carlo studies indicate th at these events also have the largest number of participants in the reaction, thus leading to a geometric description of the collision via an impact parameter.

Observables characterizing general or global event properties have been examined in some detail in the initial round of Heavy Ion Experiments.[5] Such studies focused on the means by which the incident energy is redistributed in the collision process. This includes calorimetry measurements of both forward going energy and transverse energy (E$_T$). It was found the the total multiplicity of the event is proportional to the E$_T$ produced and as such allows the characterization of a collision in geometrical terms with an impact parameter. A comparison of the E$_T$ produced in 200 GeV/A S-S collisions with that produced in 158 GeV/A Pb-Pb collisions is shown in Fig. 1.

From such measurements it is possible to estimate the energy density of the fireball following general arguments outlined by Bjorken.[6] Densities of the most central collisions approach 3 GeV fm^{-3}, indicating that the experimental conditions are in the region where a phase transition may occur.

In order to deduce whether or not thermalization has occured, it is necessary to look at single particle inclusive p_T or m_T spectra. Full thermalization will manifest itself in a purely exponential decrease in yield with increasing p_T (or m_T). It will also show up in m_T scaling which is the phenomena that all particle species appear to be at the same

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[3] For a diagram of the NA49 set-up, see "Progress in Particle Correlations at NA49", these proceedings.

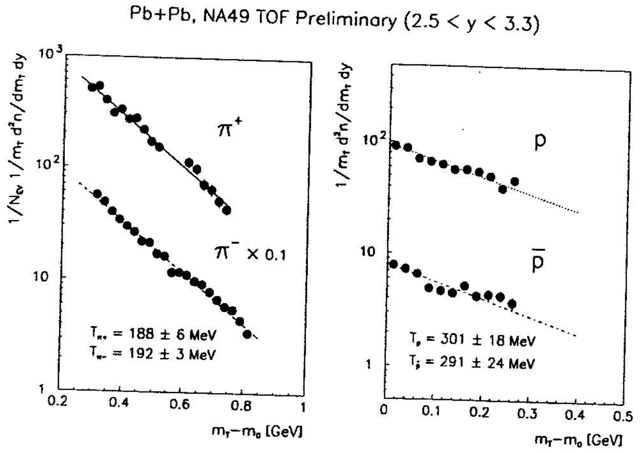

Fig. 2. M_T spectra for pions and protons identified by the TOF detectors. Not only is m_T scaling violated, but the temperatures appear unrealistically high. The inability of a hadron gas to carry this much thermal energy leads to the intr oduction of a second parameter—the flow velocity which has the effect of blue-shifting the temperature.

temperature independent of mass—that is, they all originate from the same heat bath. This does not seem to be the case in in NA49 data. This can be seen in the change of the inverse slope parameters, or "temperatures", with particle mass, as seen in Fig. 2.:

Another problem is that the temperatures are anomalously high. The Hagedorn temperature places constraints on the limits of hadron stability, and it is unphysical, in the context of this model, to have hadrons with such large temperatures. This paradox can be resolved by postulating the existence of an ordered flow which effectively blue-shifts the temperatures of the spectra so they appear hotter than they really are. This creates somewhat of a problem, as two independent parameters are manifest in a single observable. Utilizing a model dependent argument, that a maximum temperature of 165 MeV can be reached, a flow velocity can be deduced. However, what is needed is an independent observable. Correlation studies[8] can give information on the flow of the system through the evolution of the radii parameters with the pair transverse momentum (k_T). As such using this value for flow, it can be applied to the single particle spectra and a temperature assigned to it.

4. Rapidity Spectra

Another observable is that of rapidity density. This gives information on the composition of the particles emitted from the source, and the region in which they are created (periphery, central region etc.). Such information gives clues into possible mechanisms

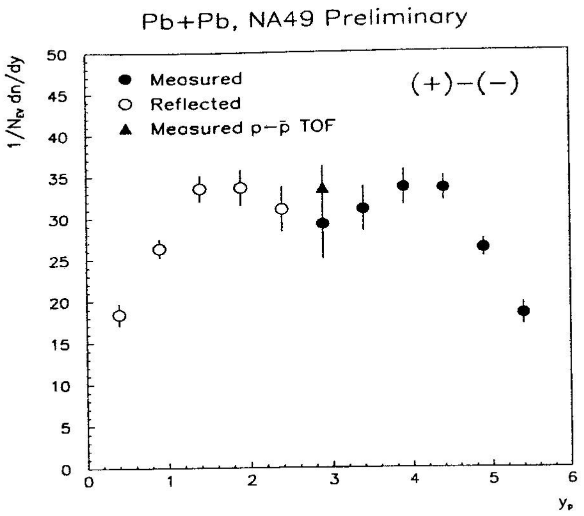

Fig. 3. "Plus-minus-minus" is a poor man's way to measure the net number of protons (with a few assumptions). Until the machinery for identifying particles via specific ionization is finally in place, this will serve as our first indication of the stopping in Pb-Pb collisions. A small drop in the yield (depletion) at mid-rapidity suggests the stopping is not as complete as that seen at the AGS.

of production. NA35 was again the first to measure such spectra over the full region of rapidity space.[9]

¿From the proton spectra, information regarding stopping and energy deposition may be extracted. The protons in AA collisions are initially far apart in rapidity—target and beam. As a collision evolves, they will gain (or lose) energy, and as such, their rapidity will shift. The amount of this shift is related to the degree of stopping present in the system. For example if the system fully stops, the proton rapidity distribution will be singly peaked at mid-rapidity; indicating the formation of a baryon rich central region. This is dominantly the case at BNL AGS. However this does not appear to be the case at CERN SPS energies. Fig. 3. presents the NA49 measurement of the net proton rapidity distribution.

If one assumes that there is no asymmetry in the production of oppositely charged particles, "plus-minus-minus" spectra approximates the number of net protons. While this is a fairly good assumption, it is violated at a small level in Pb-Pb collisions because Pb carries a net isospin. The TOF system provides a measure of identified protons at mid-rapidity. While this point is not corrected for protons due to lambda decay, it serves to give an estimate of the systematics involved. A slight depletion at

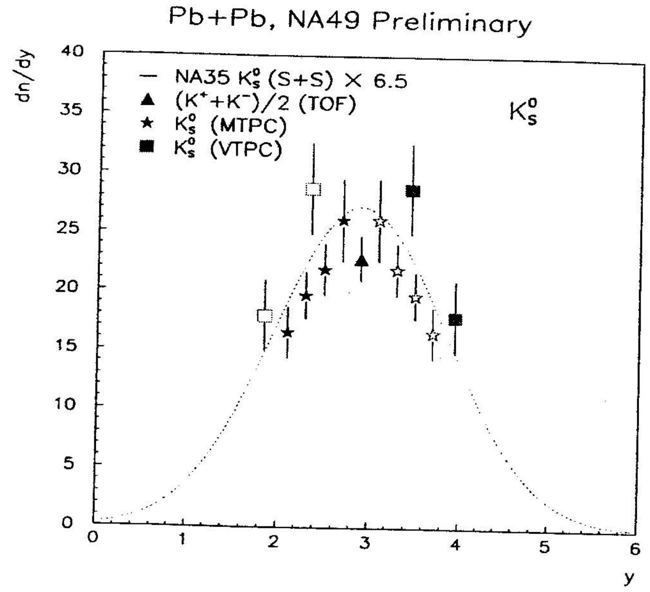

Fig. 4. Comparison between the number of Kaons seen by the various detectors at NA49. The variation in yields give some indication of the systematics between the different detectors (and methods) utilized.

mid-rapidity indicates that full stopping has not occurred.

5. Strange Particle Production

Strange particles, another speciality of NA35/NA49 experiments, have maximum yield at mid-rapidity. This can be understood through the fact that there are no valence strange quarks in the initial state, and they must all be produced from the sea. Thus, they must be produced in the hottest part of the fireball (which occurs at mid-rapidity). Preliminary measurements of the kaon yields at NA49 are shown in Fig. 4., where a variety of analysis techniques in different detectors are used, thus giving an indication of the systematic errors involved.

The kaons show the same qualitative behavior as that of the NA35 data, and seem to scale by a simple multiplicative factor. Data from Λ production will be forthcoming after studies regarding reconstruction efficiency are finalized.

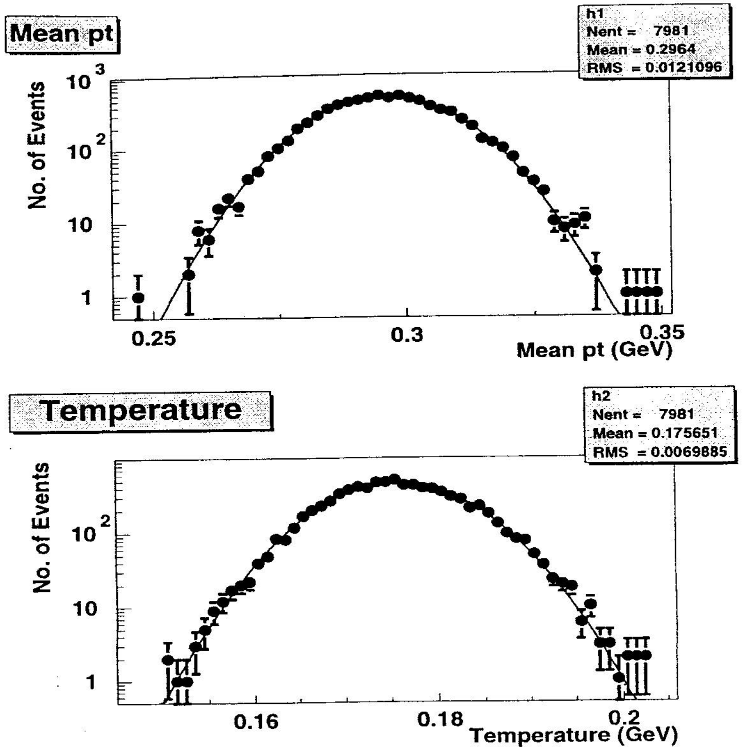

Fig. 5. First results from Event-by-Event analysis of a sample of 8000 events. No deviation in the average p_T, from a normal distribution is visible.

6. Event-by-Event Physics Observables

Although Event-by-Event analysis is in its infancy, it is perhaps instructive to look at some of the works in progress in order to get an idea of the power of the method, as well as its limitations, so that realistic expectations and interpretations can be made. Fig. 5. shows the mean p_T and "temperature" distribution for nearly 8000 events.

The philosophy of Event-by-Event physics is based on speculation that although the conditions to produce a Quark-Gluon-Plasma may occur in every event, the fact that a phase transition is a critical phenomenon implies that it may not occur in every event, but rather in a very small sub-sample of events. In this case, even though a phase transition may exhibit fluctuations in some of the physics observables, like p_T, E_T, K/π, dN/dy, conventional ensemble analyses will, in effect, average out any deviations. In this manner selecting events with certain anomalous yields (and correlating them) may provide insight into whether a transition has occured. It is also possible to use his analysis as a selection criteria to select out a sub-group of "interesting" events to be subjected to a further detailed ensemble analysis. That is, such a technique may be ensitive in isolating a certain event class of interest.

Although the above plot is produced with a very small sub-sample of events, it is notable that the form is *very* Gaussian, with no large scale fluctuations, like a double peaked structure signalling drastically different behavior. One should keep in mind hat the entire data set will be of the order of 1 Million events, so this is only a small ub-sample, but it raises some serious points. For instance, what should it be compared with and are any fluctuations that are contained therein within statistics? How sensitive must a detector be to be sensitive to these fluctuations and what physics can we deduce rom these plots? These are the kind of questions that need to be addressed in the near uture.

7. Conclusions

It is becoming clear that no single observable will provide indisputable evidence for lasma formation. It appears that if a plasma is created at SPS energies, its existence ill be uncovered only through an exhaustive, detailed study of all observables available nd of the correlations between anomalous signals. In this spirit it is necessary to have ose experimental and theoretical collaboration in order to evaluate the statistical eaning of signals. There is a lot of work to do!

cknowledgements The work presented in this paper is a compilation of NA49 results. pecial mention should go to Gunter Roland who is working on the Event-by-Event nalysis, and Peter Jones who furnished the hadron spectra.

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