STATUS REPORT

of the Relativistic Heavy Ion Programme at the CERN SPS

September 1998

The relativistic heavy ion programme at the SPS has recently seen a number of very important developments. Some of the new results, which are based on the analysis of data taken during the successful heavy ion beam time in 1996, have the quality of experimental breakthroughs. The new data provide strong support for the expectation that matter with a structure radically different from nuclear or hadronic matter is created in Pb+ Pb collisions at the SPS. Although the results stop short of furnishing unambiguous evidence for a transition to quark matter, there is growing confidence in the heavy ion community that this evidence is within reach.

The most notable achievements over the past year concern the suppression of J/ψ production, the excess emission of lepton pairs in the mass range below the ρ-resonance, the enhanced production of strange and, in particular, multi-strange hadrons, and the thermal and chemical distributions of hadrons produced in a collectively expanding fireball. We now briefly describe these achievements:

- J/ψ *suppression*

  The earlier evidence for an anomalous mechanism of J/ψ suppression in Pb+Pb collisions has been confirmed by a new analysis of the data taken by the NA50 collaboration in 1996. The new analysis, which utilizes a comparison of the J/ψ cross section as function of transverse energy E_T with the minimum bias cross section (rather than the Drell-Yan cross section), has much smaller statistical and systematic errors. The data reveal clearly that the E_T-dependence of J/ψ suppression differs strongly from that observed in lighter systems. If the analysis can be extended to smaller and larger values of E_T in the present heavy ion run, the confirmation of a threshold behaviour in a single collision system may be feasible. Such a behaviour would indicate that the QCD deconfinement transition occurs within the E_T-range covered by NA50.

- *Low-mass lepton pairs*

  The analysis of the data taken by the NA45 experiment in 1996 confirms the excess yield of e^+e^- pairs with invariant masses above twice the pion mass and below the rho mass observed earlier (by NA45 and Helios-3) in the S+Au and Pb+Au systems.

  The recent NA45 data also demonstrate that the excess is concentrated at low pair p_T and scales with the square of the charged particle multiplicity. The observed shape of the excess yield in the lepton pair mass spectrum is not consistent with expectations for $\pi^+\pi^-$ annihilation in free space. These data provide the first glimpse into the dynamics of mesons in a baryon-rich environment exceeding a temperature of 120 MeV.

  However, more precise data are needed to distinguish between different theoretical models and to determine the relation of the observed excess to chiral symmetry restoration. A significantly improved mass resolution of the NA45 spectrometer coupled with an increased data rate capability is expected to provide new high precision data from the upcoming heavy ion beam times.

- *Strangeness enhancement*

  Earlier results from NA35/NA49 of an enhanced production of strangeness in nuclear collisions (carried mostly by kaons and hyperons) have been confirmed and extended by the precise measurement of all individual hyperon yields ($\Lambda, \overline{\Lambda}, \Xi, \overline{\Xi}, \Omega, \overline{\Omega}$) in Pb+Pb collisions by the WA97 collaboration. The data cover most of the range in E_T where the anomalous J/ψ suppression is observed. These measurements show an enhancement of the hyperon yield, relative to that measured in p+Pb interactions, which grows with increasing strangeness content culminating in an enhancement by more than a factor 15 of the $\Omega + \overline{\Omega}$ yield. The enhancement is independent of E_T in the covered range, as would be expected if strange quarks are equilibrated in a deconfined and chirally symmetric quark-gluon plasma. The observed increase with strange quark content of the relative enhancement of produced hadrons contradicts expectations from hadronic rescattering models, where secondary production of multi-strange (anti)baryons is hindered by high mass thresholds and low cross sections.

- *Collective flow and hadron thermometry*

  A vast amount of evidence has been accumulated (by experiments NA44, NA49, NA52, WA97, WA98) that the hadron yields and hadron spectra from Pb+Pb collisions at the SPS can be well described by chemical and thermal equilibrium concepts. Furthermore, the collective nature of the expansion of the initially hot and dense fireball has been demonstrated by the observation of spectral slope constants which scale linearly with particle mass and, recently, by the discovery (by NA45, NA49 and WA98) of directed and elliptic flow patterns in Pb+Pb interactions. Interestingly, the chemical freeze-out, i.e. the determination of the hadron yields, appears to take place at a temperature close to where lattice QCD calculations place the phase boundary. The fact that this "chemical" temperature consistently exceeds the "kinetic" temperature (temperature for thermal freeze-out) by about 40 MeV (170 MeV versus 130 MeV) is not surprising, because reaction cross sections among hadrons, which drive hadrochemistry, are falling much faster with decreasing temperature than elastic cross sections, which maintain thermal equilibrium.

  High-statistics measurements of identical particle correlations by the NA44 and NA49 experiments have helped to separate the contributions of temperature and collective flow to the measured hadron spectra. Furthermore, such correlation data have yielded first estimates of the overall life-time of the fireball. Two hadronic states, the Ω baryon and the J/ψ, appear to deviate from the slope systematics established for all other hadrons: they do not seem to be affected by the build-up of collective radial flow in the expansion of the fireball. This may be due to their low elastic scattering cross sections with hadrons composed of light quarks, making their respective enhancement or anomalous suppression again very hard to understand in a hadronic model of the Pb+Pb reaction. Note that large inelastic cross sections, as are required, e.g., in the "co-mover" interpretation for the observed J/ψ suppression, are inconsistent with small elastic cross sections (through unitarity). Furthermore, chemical freeze-out close to the phase boundary lends support, albeit indirectly, to the interpretation that, prior to freeze-out, the system was in a partonic phase.

The near-term outlook is as follows:

NA50 and NA57 will attempt to extend the E_T-range over which precision data for J/ψ suppression and Ω/Ξ enhancement can be taken in Pb+Pb. It appears highly desirable for both experiments to take data from a collision system with $\sqrt{A_1 A_2} \approx 100$ as soon as possible, to extend the coverage down to even smaller values of E_T. Note that J/ψ measurements cannot be performed at a significantly reduced beam energy (such as 40 GeV/nucleon discussed below) because of the drastic reduction in cross section.

NA45 is ready for data taking with strongly improved mass resolution, hoping to identify the pair decay of the ω-meson and to improve significantly the systematic errors of the e^+e^- pair spectrum. The NA50 pixel detector upgrade would provide an independent measurement of the low mass dilepton yield with approximately similar statistics but completely different background sources.

NA45, NA49, and NA57 plan to study the characteristics of hadron production and lepton pair continuum at a lower beam energy, such as 40 GeV/nucleon. At this beam energy the ratio of baryon density to energy density is increased by about a factor of 3 compared to the situation at full SPS energy. This should have consequences for the in-medium modifications of vector mesons (and thus the low mass part of the dilepton spectrum). This lower energy is also of large interest for the study of azimuthal anisotropies (flow) and of multistrange hadron production because the energy is close to where one expects to enter the QGP phase (the "soft point" in the equation of state).

Finally we would like to mention open charm as an area presently not covered by any of the existing experiments. Open charm production is closely related to charmonium production. There are indirect indications (by NA50) for an enhancement (compared to A^2 scaling of pp results) in open charm production. A direct measurement is needed for confirmation, and the feasibility should be seriously studied.

This report was prepared by Berndt Mueller and Peter Braun-Munzinger, based on the discussions held in Chamonix (September 25-27, 1998) on the results presently available from the SPS Heavy Ion Programme.