Status of the CERN SPS relativistic Heavy Ion beam program

At the "Quark Matter99" conference in Torino (Italy) the scientific community reflected upon the status of the search for quark matter. The outcome can be briefly summarized as follows: in attempting a summary after 5 years of relativistic Lead beam studies at the SPS (including results from the previous Sulphur beam program) we conclude that most of the experimental results are consistent with the hypothesis that a non-hadronic, new QCD phase is indeed created at SPS energy. The data cover a wide variety of complementary aspects of this assumption. The key experimental findings are sketched below. They are not, each by themselves, providing unambigious proof but each of them support different facets of the consequences expected to arise from a transient QCD state formed early in the reaction dynamics of heavy nucleus collisions.

Recent lattice QCD calculation predict the phase transformation between partons and hadrons to occur at an energy density of about 1-1.5 GeV per cubic Fermi. Experimental estimates from calorimetric study of bulk transverse energy production and from hadron yield measurement in full phase space indicate that this density is reached in sulphur induced reactions, and far surpassed in central Pb+Pb collisions [NA49, WA98].

Quite in line with this observation we find the predicted pattern of charmonium suppression, due to a transient partonic medium, to occur here [NA50]. The Ψ' yield fades away in central sulphur-nucleus collisions already (which may, however, have reasons other than QCD Debye screening) while the J/Ψ yield starts disappearing in central Pb collisions only, in line with the twice smaller radius of the latter state. Actually the J/Ψ is harder to break up than most other hadrons, thus offering the most significant signal of a transient partonic phase.

Assuming that a transient partonic phase causes the observed J/Ψ breakup it should further manifest itself in the physics observables reflecting its eventual transition back to hadrons. In fact the total strangeness content of the final hadronic phase is consistent with the input into hadronization expected from a partonic phase [WA97, NA49]. Moreover the production ratios of hyperons and anti-hyperons seem to reflect a flavour coalescence mechanism typical of a non QCD perturbative quark-hadron transition.

A further fingerprint [NA44, NA49, WA97] of the hadronization process is present in the overall set of hadronic yield ratios which reveals a characteristic regularity.This observable order among all the produced hadrons serves as a "thermometer" for the phase transition which gives birth to the hadrons, in their various species from pions to Omega hyperons. They are pinned down as far as their various relative contributions are concerned by just a few significant parameters, temperature and energy density, characterizing their environment at birth. The apparent thermal equilibrium of all species can thus be understood to be a consequence of the hadronization phase transformation. From these observations the phase boundary appears to be located at about 180 MeV, corresponding to an energy density of about 1 GeV/fm^3 in accord with the lattice QCD prediction. We get a first impression of detailed features of the parton to hadron transition from the observation that individual central Pb collision events exhibit no sign of fluctuations in the hadronic population and temperature [NA49], which are prominent in hadronic collisions.

Central Pb+Pb collisions have also facilitated a first precision analysis of two pion Bose-Einstein correlation data and hadronic transverse mass spectra, in terms of collective space-time parameters characterizing the "explosive" expansion dynamics of the initial dense interaction volume. The overall collision time from formation of the "fireball" to decoupling is about 10 fm/c, long in comparison to a typical partonic relaxation time scale, of about 2 fm/c. The expanding system develops strong collective velocity fields, with transverse velocity of ca. 0.6 c, while cooling down to about 120 MeV at freezeout. These findings agree with a picture of an initial partonic cascade ending in a hadronization phase from which hadrons expand in a "blast wave" mode until decoupling [NA44, NA49, WA98].

The features of the initial, dense hadronic phase, right after the hadronization transition, may also set the stage for strong in-medium effects expected to modify vector meson properties such as mass, width, and branching ratios. In fact drastic changes are observed in electron-positron pair mass spectra that reflect the in-medium meson properties[NA34, NA45]. We might see in these data remnants of chiral symmetry restoration which is expected to occur in ultradense matter, concurrent with the QCD deconfinement transition reflected in the other above observables. These observations are being further persued with benefits from improved NA45 experimental facilities.

In summary the SPS experiments have gathered a multitude of crucial observations that together suggest the existence of a bulk deconfined state, of a partonic makeup, governing the early dynamics of the high energy density "fireball" created in central nucleus-nucleus collisions at the SPS energy, $\sqrt{s}$=18-20 GeV. The experimental findings may be summarized by the tentative conclusions that:

1. A primordial non-hadronic bulk phase of strongly interacting matter is realized at energy density far exceeding 1.0 GeV per cubic Fermi.

2. This state undergoes a parton to hadron phase transition at about 170 to 180 MeV, the data providing first glimpses at its non-perturbative QCD mechanism . This transition thus occurs at about 1 GeV per cubic Fermi - in accord with lattice QCD theory.

3. The initial, dense hadronic medium (right after hadronization) reveals a microscopic makeup characteristic of the conditions predicted by QCD chiral symmetry restoration, thus sheding first light on the suspected coincidence of the deconfinement and chiral restoration QCD transition.

The present SPS experiments, and corresponding theory developments will attempt to ascertain these points of view in the upcoming year of fixed target SPS runs, then to merge in confronting the research potential of the "QCD plasma factories" presented by collider experiments at vastly extended energy: RHIC at Brookhaven (startup 2000) and LHC at CERN (startup 2005).

The Proceedings of the last Quark Matter Conference, held at Torino/Italy in May 99 (Quark Matter99) have appereared in the journal Nuclear Physics Series A, Vol. 661 (1999), Elsevier publ.. These proceedings present the detailed material, the highlights of which are tentatively summarized above.