6 THE HEAVY-ION PHYSICS PROGRAMME AT THE CERN OMEGA SPECTROMETER

Federico Antinori
INFN Padova, Italy

Abstract

In recent years, a series of experiments at the CERN OMEGA spectrometer (WA85, WA94, WA97) have studied the production of strange particles (kaons, Λ, Ξ^-, Ω^- and their antiparticles) in nucleus–nucleus and proton–nucleus reactions. I summarize the results of WA85 and WA94 and the current status of the WA97 analysis: the production of strange particles is enhanced when going from proton–nucleus to nucleus–nucleus collisions, and the effect is larger for particles of higher strangeness content, as expected in the case of quark–gluon plasma formation. I illustrate the plans for a continuation of this line of research after the closing of the OMEGA spectrometer.

6.1 Introduction

A large part of the activity at the OMEGA spectrometer in recent years was devoted to heavy-ion physics. Like the glueball search programme described by Andrew Kirk in the previous contribution, the heavy-ion programme explores the ‘soft frontier’ of strong interaction, by testing predictions coming from the non-perturbative sector of Quantum ChromoDynamics (QCD).

Lattice QCD predicts that when the energy density of a system of hadrons exceeds a critical value of the order of a few GeV/fm^3, the system should undergo a phase transition from standard hadronic matter to a Quark–Gluon Plasma (QGP). In the new phase quarks and gluons are no longer bound into colourless hadrons (deconfinement) and quark masses revert from the constituent value they have inside hadrons to the current value they have in the Lagrangian (partial restoration of chiral symmetry).

By colliding two heavy nuclei at high energy we create an extended strongly interacting system, with an energy density in the range where the QGP phase transition is expected to take place. The study of such a system is of fundamental interest for the understanding of the properties of the QCD vacuum, which are thought to be responsible for the phenomenon of colour confinement. It is also relevant to other fields such as Cosmology and Astrophysics.

6.2 Strangeness as a QGP signal

Strangeness is expected to be a good probe in the search for the QGP phase transition. In standard hadronic collisions, the production of strange particles is known to be suppressed due to the large values of the production thresholds, by roughly a factor 0.3 for each unit of strangeness. In contrast, in the deconfined phase one expects abundant production of $s\bar{s}$ pairs by gluon–gluon fusion, since the value of the current mass of the strange quark is of the order of the critical temperature (~ 150 MeV). This is expected to lead, after rehadronization, to an enhancement in the abundances of the various species of strange particles with respect to those found in standard hadronic collisions. The effect should be more pronounced for particles of higher strangeness content [1].

In principle, secondary interactions in the large hadronic fireball created in the nucleus–nucleus collision might also produce a strange-particle enhancement, even in the absence of an initial QGP phase. However, especially for multi-strange antibaryons, these processes are estimated to be too slow (with characteristic time-scales of the order of 100 fm/*c*) to be of importance on the collision time-scale (a few fm/*c*) [2].

6.3 WA85 and WA94

WA85 (1987–1990) and WA94 (1991–1993) were the first two heavy-ion experiments performed at the OMEGA spectrometer. Both made use of the 200 GeV/*c* per nucleon SPS sulphur beam, and were based on a system of 'butterfly' Multi-Wire Proportional Chambers (MWPC) for tracking. These were standard OMEGA chambers modified in such a way as to be sensitive only to a few particles emitted at central rapidity and $p_\perp > 1$ GeV/*c* out of the several hundred produced in the collisions.

WA85 [3] observed an enhancement in the production of strange particles when going from p–W to S–W collisions. As shown in Fig. 6.1, the yields of different species of strange particles (normalized to the yield of negatively charged particles, known to be mostly pions) increase when going from p–W to S–W collisions, by a factor between 1 and 2 for $|s| = 1$ particles and by a factor between 2 and 3 for $|s| = 2$ particles.

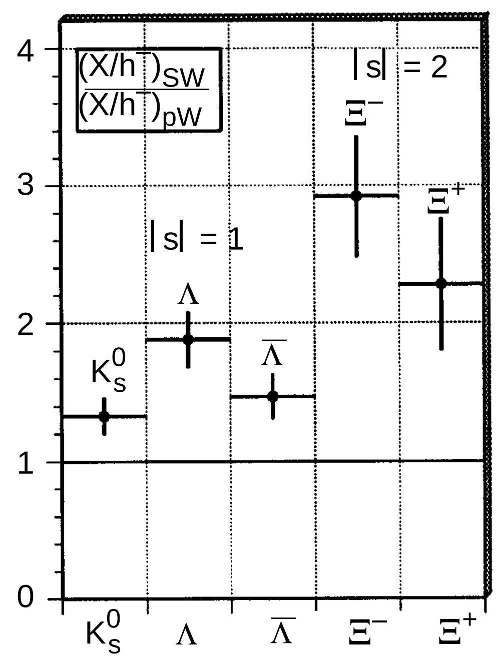

Fig. 6.1: WA85 data on the enhancement of strange particles (normalized to the yield of negative particles) in S–W relative to p–W collisions.

WA94 [4] obtained similar results in the comparison of strangeness production in p–S and S–S collisions. The comparison of WA85 and WA94 data on the Ξ/Λ and $\overline{\Xi}/\overline{\Lambda}$ ratios with available pp data from the AFS [5] experiment is shown in Fig. 6.2.

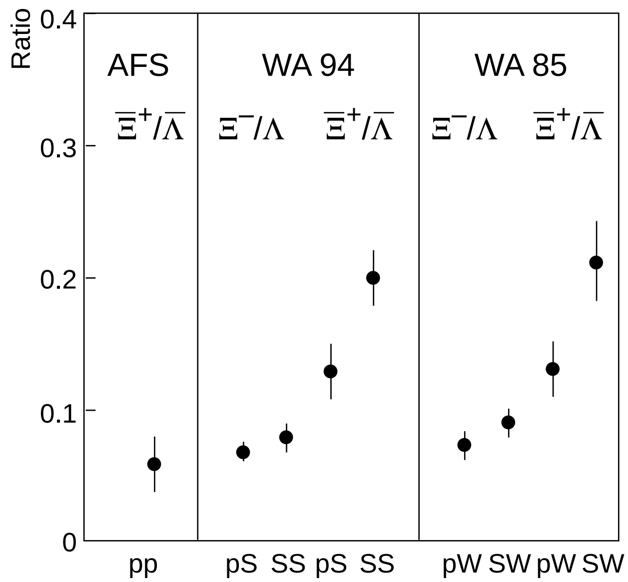

Fig. 6.2: Compilation of AFS, WA94 and WA85 data on Ξ/Λ ratios.

6.4 Status of the WA97 analysis

The advent of the Pb beams at CERN allows this study to be extended to the really heavy Pb–Pb system. In order to cope with the increased track density, the butterfly chambers were replaced by a silicon telescope made of Si microstrip detectors with a pitch of 50 µm and of Si pixel detectors with a pixel size of 75 µm × 500 µm, developed in a collaboration between WA97 and the CERN Microelectronics group [6]. With seven 5 × 5 cm^2 planes of pixel detectors, the telescope acts as a Pixel Tracking Chamber (PTC) with about 0.5×10^6 detecting elements for precise coordinate measurements.

WA97 has collected K and Λ ($|s| = 1$), Ξ ($|s| = 2$) and Ω ($|s| = 3$) samples from both p–Pb and Pb–Pb collisions, so that the study can now be extended to the full $|s| = 1, 2, 3$ range. The analysis of WA97 data is in progress. Preliminary results, which are summarized later in this section, indicate that Ω production is in turn significantly enhanced relative to Ξ production when going from p–Pb to Pb–Pb collisions [7], confirming for $|s| = 3$ particles the trend observed already in WA85 and WA94 for $|s| = 1, 2$.

The experimental set-up, shown schematically in Fig. 6.3, is described in detail in Ref. [8]. Multiplicity detectors located near the Pb target provide a centrality trigger selecting about 30% of the Pb–Pb cross-section. In addition, they provide detailed information allowing off-line study of how particle ratios depend on the event multiplicity. The reconstruction of tracks is done in the compact part of the PTC where the silicon planes are closely packed over a distance of 30 cm. The momentum resolution of fast tracks is improved using the lever-arm detectors which consist of additional pixel and microstrip planes and of three MWPCs with a pad cathode read-out.

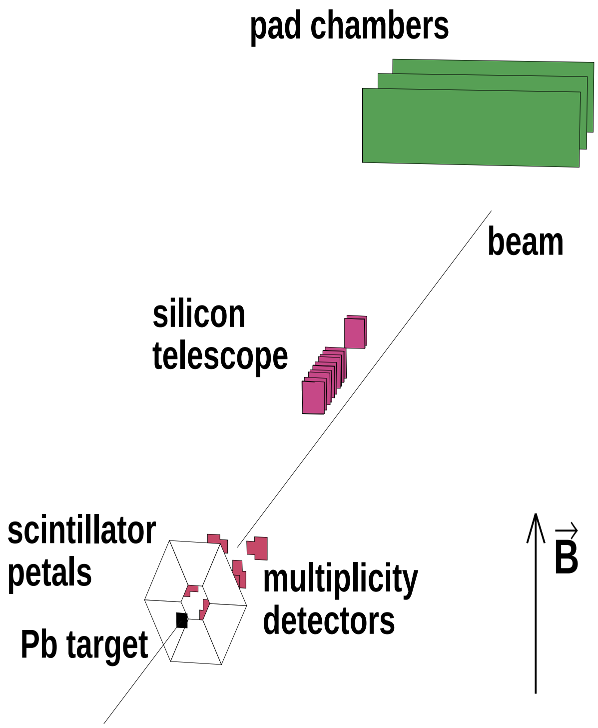

Fig. 6.3: WA97 set-up in the OMEGA magnet.

To illustrate visually the capability of the PTC to cope with high-multiplicity events, Fig. 6.4 shows a reconstructed Pb–Pb event recorded in the absence of magnetic field. The event contains 153 reconstructed tracks, corresponding to an occupancy of about 0.2% of the 72 000 channels provided by each pixel-detector plane.

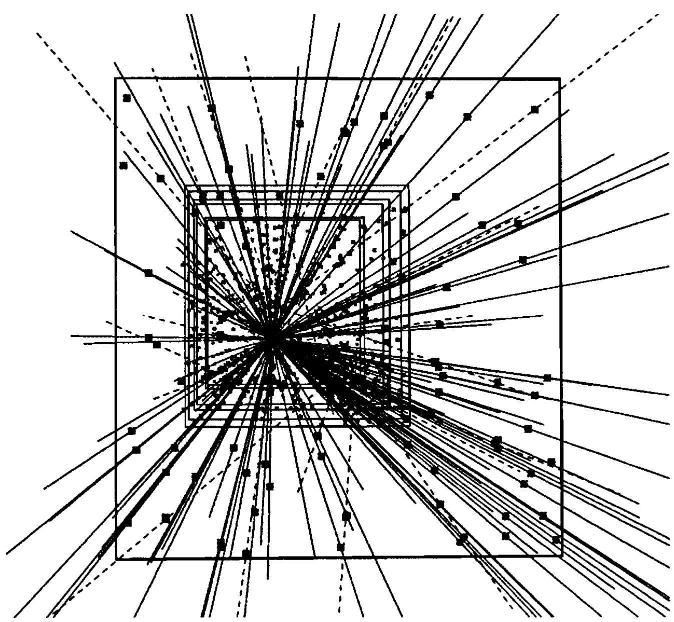

Fig. 6.4: WA97 no-field event with 153 reconstructed tracks in the pixel tracking chamber.

The geometrical acceptance of the apparatus covers the region of central rapidity ($2.5 < y_L < 3.4$) and medium transverse momentum ($p_\perp > 0.5$ GeV/c) and is the same for particles and antiparticles.

The results summarized here are based on the analysis of two data samples collected by WA97 during the 1995 run with different experimental conditions:

– 120×10^6 p–Pb events taken with the PTC placed 90 cm from the target and under the trigger requirement of having at least two charged particles in the PTC.

– 20×10^6 Pb–Pb events[1] taken with the PTC 60 cm from the target. The average number of reconstructed tracks in the PTC was ~ 20.

The Ω^- and Ξ^- hyperons (and the corresponding antihyperons) are identified by reconstructing their two-step decays containing only charged particles in the final state, i.e.

$$\Xi^- \to \Lambda\pi^-, \Omega^- \to \Lambda K^- \; (\Lambda \to p\pi^-) \, .$$

Figure 6.5 shows the uncorrected $\Xi^- + \overline{\Xi}^+$ and $\Omega^- + \overline{\Omega}^+$ signals for the p–Pb and Pb–Pb data samples.

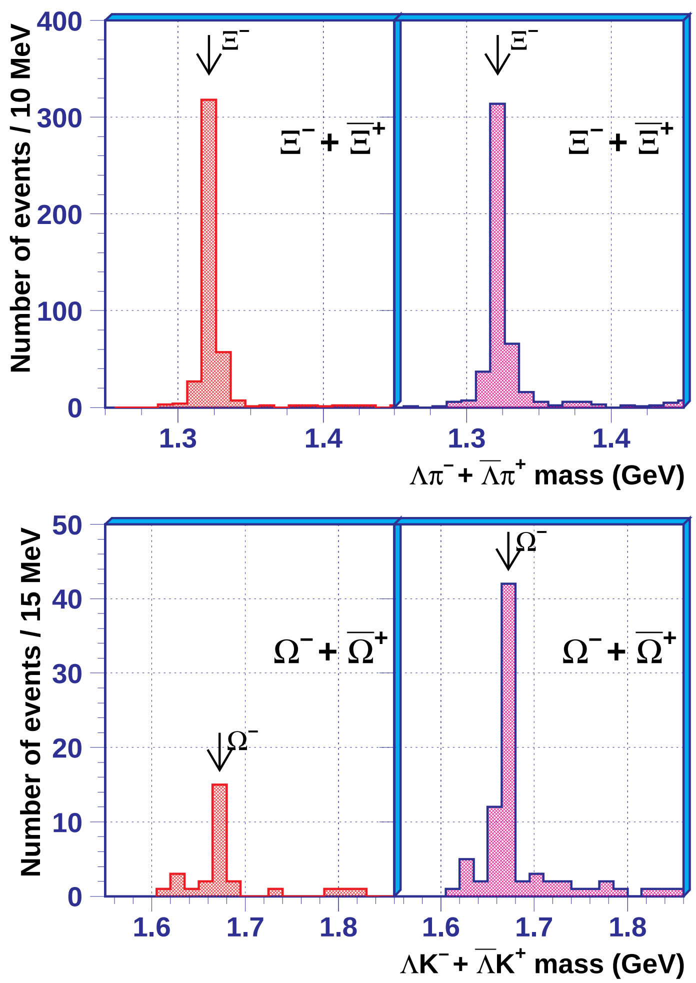

Fig. 6.5: Uncorrected Ξ and Ω signals in p–Pb and Pb–Pb data.

1. This sample represents a fraction of the total statistics of about 100×10^6 triggers. Analysis of the remaining data is in progress.

At the present stage of analysis, the relative normalization between the p–Pb and Pb–Pb samples has not yet been determined. Therefore one can only compare the observed Ω/Ξ ratios.

The geometrical arrangement was different for the p–Pb and Pb–Pb data-taking. The integrated acceptance for the Ω/Ξ ratio was higher by $\simeq$ 10% for the Pb–Pb sample. One assumes the reconstruction efficiencies for Ξ and Ω to be the same (for a given data sample) and therefore to cancel in the Ω/Ξ ratio. This assumption is based on the fact that both particles have the same decay topology and the track reconstruction efficiency depends only weakly on its momentum. Preliminary calculations performed for the limited Pb–Pb data sample are consistent with this assumption.

Figure 6.5 shows a striking difference between Ω/Ξ ratios in the p–Pb and the Pb–Pb samples. If the Ω/Ξ production ratio were to be the same in p–Pb as in Pb–Pb collisions, one would expect an Ω signal in the p–Pb sample significantly stronger than the one observed. A preliminary estimate of the Ξ^- and Ω^- production cross-sections in p–Pb and Pb–Pb reactions indicates a significantly enhanced Ω^- production in Pb–Pb collisions. Taking into account the integrated geometrical acceptance and assuming the same reconstruction efficiency for Ξ and Ω we obtain

$$\frac{\left(\Omega^- + \overline{\Omega}^+ / \Xi^- + \overline{\Xi}^+\right)_{\mathrm{Pb-Pb}}}{\left(\Omega^- + \overline{\Omega}^+ / \Xi^- + \overline{\Xi}^+\right)_{\mathrm{Pb-Pb}}} \simeq 3 \ .$$

A calculation using Poisson statistics indicates that the above ratio is greater than 2 at the 95% confidence level. Full acceptance and efficiency corrections are being calculated, and will allow the Ω/Ξ ratios to be measured separately in p–Pb and Pb–Pb.

6.5 Outlook: NA57 and Alice

The progressive enhancement in the production of hyperons with increasing strangeness content suggests a large initial strangeness density, as expected for a system in the QGP phase. Recent studies of hadron abundancies in nucleus–nucleus collisions [9] indicate that the temperatures and baryon densities reached are close to where the phase boundary between hadronic matter and QGP is expected to be.

In other words, it is conceivable that we are indeed on the QGP side of the boundary, and that this is the origin of the strangeness enhancement pattern observed. In order to further investigate this matter, a new experiment has recently been proposed and approved (NA57) by a collaboration which includes most of the WA97 institutes. The purpose of NA57 is to extend the physics scope of WA97 by comparing the production of strange and multi-strange particles in nucleus–nucleus collisions at the present (160·*A* GeV/*c*) and at a lower beam momentum ($\simeq$ 40·*A* GeV/*c*). Assuming that at 160·*A* GeV/*c* we are close to the phase boundary, a significant drop in the Ω/Ξ ratio towards the value it has in proton-induced reactions going from 160·*A* GeV/*c* to 40·*A* GeV/*c* would suggest that at 40·*A* GeV/*c* we have moved away from the phase boundary.

The set-up of NA57 will consist of a silicon telescope similar to the one of WA97, installed inside the Goliath magnet on the H4 beam line at the SPS. The detector development activity started at OMEGA will also continue: there are plans to improve the NA57 apparatus by employing prototypes of the Si microstrip and Si pixel detectors under development for use in the ALICE heavy-ion experiment at the CERN Large Hadron Collider (LHC). These detectors will provide ALICE with the necessary secondary vertex detection capability for the measurement of charm (and strangeness) production in Pb–Pb collisions at LHC energy.

6.6 Conclusion

The heavy-ion physics programme at the OMEGA spectrometer has established a pattern of enhancement in the production of strange particles of the kind expected from QGP formation. This result calls for further investigation: the programme does not end with the closing of the OMEGA spectrometer, and will continue in the North Area.

Si pixel technology has reached maturity through its first application at OMEGA in WA97. This technique is ideal for secondary vertex detection in high track density environments, and therefore for the study of non-light flavour production in nucleus–nucleus collisions.

A beautiful physics instrument retires, but it leaves as its legacy a promising line of research from here, through NA57, into the LHC era.

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