DILEPTON AND CHARMONIUM PRODUCTION AT THE SPS

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Experiments measuring lepton pairs have played an important role in the SPS heavy-ion program since its very beginning, in 1986. We start by shortly reviewing the present situation in this field. Then, we describe the NA60 experiment, that has been designed in order to answer specific questions which remained open after the previous SPS experiments. NA60 has taken Indium–Indium data in 2003 and their analysis is presently ongoing. Preliminary results on J/ψ suppression in In-In collisions will be shown, as well as hints of the quality of the results that can be expected for the study of low and intermediate mass dimuons. Prospects for the future will also be shortly discussed.

1 Introduction

The studies of high energy nuclear collisions done at the SPS between 1986 and 2000 have given strong indications that, above a certain critical value of the colliding nuclear mass or of the collision centrality, the partons produced in the initial stage of high energy heavy–ion collisions undergo a transition to a system of interacting deconfined partons.

However, the understanding of some of the most interesting observations made in the SPS heavy–ion program requires further work, and this work has to be pursued at the SPS. In particular, three specific questions raised by the previous experiments, all of them addressing physics topics accessible through the measurement of dileptons, must be answered.

The first question concerns the interpretation of the dimuon mass spectrum between the ϕ and the J/ψ resonances. It has been shown by Helios-3 and NA50 that in p-A collisions it is well described by Drell-Yan and simultaneous semi-leptonic decays of D mesons, as expected. On the contrary, in A-A collisions the dimuon mass spectrum shows an excess which grows with the number of nucleons participating in the interaction. Two interpretations of this excess have been considered: it can be due to an unexpected enhancement of charm production or to thermal dimuons emitted from the QGP phase [1].

Secondly, the CERES experiment measured the dielectron invariant mass spectrum in S-Au and Pb-Au collisions. A comparison with the expected sources (mainly light meson decays, which describe the proton data) shows an excess in the mass range 0.2–0.7 GeV/c^2. This observation [2] has been interpreted as an indication of changes in the mass and decay width of the ρ meson, maybe due to partial restoration of the chiral symmetry. However, this result suffers from lack of statistics and a poor signal-to-background ratio.

Finally, the J/ψ suppression, as a signature of the formation of a deconfined state, has been studied by NA38 and NA50. In Pb-Pb collisions the J/ψ production pattern, as a function of the collision centrality, shows that above a certain centrality threshold the J/ψ yield is considerably lower than expected from the "nuclear absorption" curve, derived from proton-nucleus and light ions data [3]. One of the current interpretations of this result is that the dense and hot medium formed in the collisions dissolves the χ_c resonance, leading to the disappearance of the fraction ($\sim$ 30 %) of J/ψ mesons that would otherwise originate from χ_c decays. Several questions remain open. What is the physical variable driving the J/ψ suppression? Is it the number of participant nucleons? Or the local energy density? Or the average length of nuclear matter, L, traversed by the charmonium state? Are the nuclear dependences of the J/ψ and χ_c yields the same?

2 The NA60 experiment

To solve the questions outlined in the previous section, a new dimuon experiment, NA60, has been explicitly designed. With respect to previous experiments, NA60 has strongly improved the dilepton detection techniques [4,5]. In particular, a very good muon pair mass resolution and vertex identification accuracy have been obtained, in order to disentangle the various muon sources and better resolve the signal resonances. Furthermore, by taking data for In–In collisions, a lighter colliding system than Pb–Pb, NA60 investigates the onset of the J/ψ anomalous suppression with the aim of determining the physics variable driving the suppression mechanism.

In terms of detector layout, the NA60 experiment complements the Muon Spectrometer and Zero Degree Calorimeter (ZDC) inherited from the NA50 experiment with a completely new target region, where silicon micro-strip and pixel detectors, integrated in a 2.5 T dipole magnet, allow us to track the charged particles produced in the collisions and accurately determine primary and secondary vertices. By matching the muons measured in the muon spectrometer to tracks in the silicon vertex telescope, simultaneously using information on coordinates and momentum, we can overcome the uncertainties introduced by multiple scattering and energy loss fluctuations, induced by the crossing of the hadron absorber. Besides the improvement in dimuon mass resolution, we are also able to accurately determine the origin of the muons, and separate prompt dimuons (Drell-Yan, thermal) from the muon pairs due to decays of D mesons.

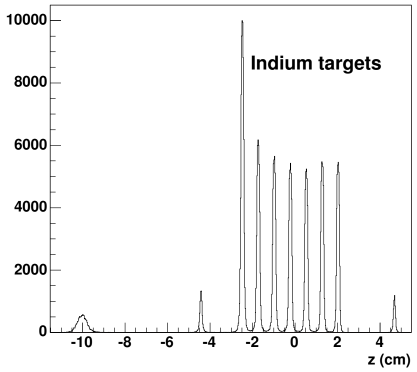

Figure 1. The z coordinate of the interaction point as measured by the vertex telescope.

3 First results from the study of In-In collisions

In 2003, during a five-week long run, about 4×10^{12} Indium ions (with an energy of 158 GeV per nucleon) were delivered and more than 200 million dimuon events were collected. In parallel, minimum bias events, requiring only an energy deposition in the ZDC exceeding a very low threshold or an incident ion crossing the beam tracker, have been acquired for normalization purposes. The vertexing accuracy reached by the pixel telescope can be appreciated in Fig. 1, which shows the distribution of the interaction vertices along the beam axis. We can distinguish, with $\sim$ 200 μm resolution, the seven Indium targets between the two vacuum box windows. We can also see a beam tracker plane, 10 cm upstream of the target centre.

In Fig. 2 we show the extracted signal dimuon spectrum in the region of the ω and ϕ resonances, on the basis of around 1% of the collected statistics. It shows a mass resolution around 20–25 MeV. The combinatorial background resulting from π and K decays was estimated through a mixed–event technique, based on the like–sign muon pairs. The analysis of low mass dimuon production can be done down to very low transverse mo-

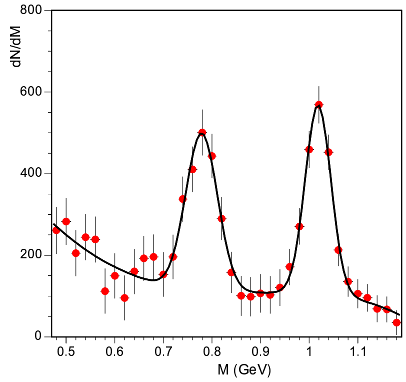

Figure 2. The low mass dimuon signal after track matching.

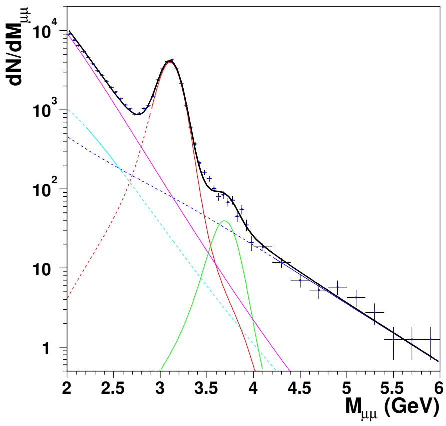

Figure 3. Opposite sign muon dimuon spectrum for $m_{\mu\mu} > 2$ GeV/c^2. The various sources contributing to the invariant mass distribution are shown.

mentum and as a function of the collision centrality. First physics results will be available very soon.

Finally, a preliminary study of the J/ψ suppression in In–In collision has been performed using roughly half of the total collected dimuon statistics.

The muon track matching is not so crucial for the analysis of the J/ψ meson, clearly visible over the underlying continuum even with a mass resolution of 100 MeV, as can be seen in Fig. 3. A severe event selection procedure has been applied. This eliminates pile-up and events with interactions out of the targets. Refined quality cuts are now under study, in order to maximize the available statistics for the extraction of physics results.

The high mass spectrum shows the J/ψ and ψ' resonances sitting on a continuum composed of Drell–Yan dimuons and of muon pairs from decays of D mesons, besides the combinatorial background from π and K decays, which we determine from the measured like–sign muon pairs. In order to extract the ratio between the J/ψ and the Drell–Yan production cross–sections, integrated over the range E_{ZDC} <15 TeV, we fit the opposite–sign dimuon mass distribution to a superposition of the aforementioned contributions. The mass distributions for the various processes are evaluated through a detailed Monte Carlo simulation, using Pythia with MRS–A (low Q^2) parton densities for event generation and GEANT for tracking through the experimental apparatus. The events are then reconstructed like the real data. From the Monte-Carlo calculation we can deduce the J/ψ and Drell–Yan acceptances, A_ψ=12.4% and $A_{DY(2.9<m_{\mu\mu}<4.5)}$=13.4%, in our phase space window.

In order to compare with previous results, published by the NA38 and NA50 experiments, obtained in p-A, S-U, and Pb-Pb collisions, we refer our In-In result to the Drell–Yan production cross section integrated in the mass domain between 2.9 and 4.5 GeV. Our analysis [6] gives $B_{J/\psi\to\mu\mu}\sigma_{J/\psi}/\sigma_{DY} = 19.5 \pm 1.6$.

Figure 4 shows how the In-In point compares to the previously established J/ψ suppression pattern, as a function of L, the thickness of nuclear matter traversed by the charmonium state. Figure 5 shows the same measurements as a function of the number of nucleons involved in the collision, $N_{\rm part}$. In this figure the data points are divided by the normal nuclear absorption curve, determined from the p–A measurements, which can be seen as a continuous line in Fig. 4. The In–In measurement, when normalized to the absorption curve, gives the value 0.87 ± 0.07. Once all the collected Indium data will be fully analyzed, we should be able to probe the J/ψ suppression pattern as a function of centrality, in the ranges 5.5–7.8 fm in L and 50–200 in $N_{\rm part}$. By comparing the In-In and Pb-Pb patterns as a function of different centrality variables, we should understand which is the variable and, therefore, the physics mechanism, driving the J/ψ suppression. Finally, to fully exploit the available J/ψ statistics, we are investigating the possibility of replacing, as a reference process, the low statistics Drell–Yan with an equivalent estimator computed from the large available sample of minimum bias events that has been collected.

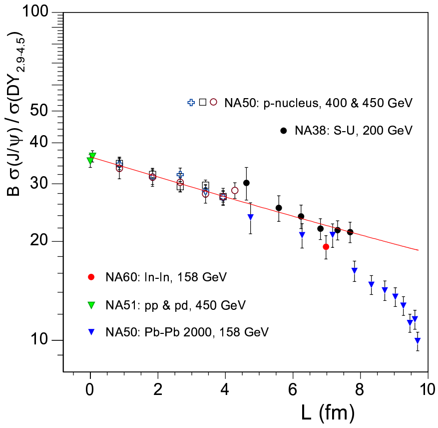

Figure 4. J/ψ suppression pattern versus L.

4 Conclusions and future

After 18 years, dilepton production at the SPS is still a hot and lively physics subject, its study now being carried on by NA60. Preliminary results from the In-In run show a substantial improvement in the quality of the measurements with respect to previous experiments, which should lead to significant impacts in our understanding of the low and intermediate mass dilepton production, as well as of the origin of the anomalous J/ψ suppression. At the time this paper is being written, a high statistics proton–nucleus run is under way. At the end of the data acquisition NA60 will have an accurate reference baseline, with which we will compare the heavy–ion results.

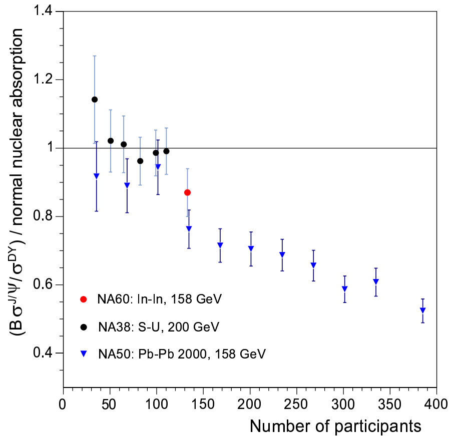

Figure 5. J/ψ suppression pattern versus N_{part}.

Acknowledgments

A full list of authors can be found at *http://na60.cern.ch.*

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