

PROMPT DIMUONS AND D MESON PRODUCTION IN HEAVY-ION COLLISIONS AT THE SPS

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NA60, a follow-up of NA38/50 at the CERN-SPS, is a third generation heavy ion experiment finally approved in November 2000 for heavy-ion runs in 2002 and 2003. This article will report about the main motivations which lead to this experiment, the main detector concept and the foreseen physics performance.

1 Physics motivation

A very large amount of experimental results were obtained by the CERN SPS experiments since 1986. A tentative summary has been proposed ¹, basically saying that “the combined results provide compelling evidence for the existence of a new state of matter, featuring many of the characteristics of the primordial soup in which quarks and gluons existed before they clumped together as the universe cooled down”. Although this evidence is accepted by a large fraction of the Heavy-Ion community, several questions remain unclear. Some of these questions will be addressed by NA60, including a better understanding of the J/ψ suppression, by running different collision systems like In-In and Pb-Pb, as well as the measurement of the χ_c production in p-N collisions. This article will concentrate on the main motivations of the experiment, namely the clarification of the intermediate- and low-mass dilepton enhancement. An overview of all physics motivations can be found in Ref. 2 and 3.

1.1 Intermediate mass dimuons

The NA38 and NA50 experiments have studied the production of dileptons in the mass window between the ϕ and the J/ψ peaks, as a superposition of Drell-Yan dimuons and simultaneous semileptonic decays of D and \bar{D} mesons, after subtraction of the combinatorial background from pion and kaon decays ⁴. The dimuon mass spectra measured in p-A collisions are very well reproduced taking the high mass region to normalize the Drell-Yan component and an open charm cross-section in good agreement with direct measurements made by other experiments. On the contrary, the superposition of Drell-Yan and open charm contributions, with the nucleon-nucleon absolute cross sections scaled with the product of the mass numbers of the projectile and target nuclei (as expected for hard processes), fails to properly describe the dimuon yield measured in ion collisions.

The data can be properly reproduced by simply increasing the open charm yield, with a scaling factor that grows linearly with the number of nucleons participating in the collision, reaching a factor 3 in the most central Pb-Pb collisions. The observed excess can also be due to the production of thermal dimuons, a signal that was the original motivation for the NA38

experiment. In particular, the intermediate mass dimuons produced in the most central Pb-Pb collisions are well reproduced by adding thermal radiation, calculated according to the model of Ref. 5, to the Drell-Yan and charm contributions normally extrapolated from nucleon-nucleon collisions. This model explicitly includes a QGP phase transition with a critical temperature of 175 MeV. The best description of the data is obtained using ~ 250 MeV as the initial temperature of the QGP medium radiating the virtual photons.

The presently available data cannot distinguish between an absolute enhancement of charm production and the emission of thermal dilepton radiation. The clarification of the nature of the physics process behind the observed excess is one of the remaining questions of the CERN heavy-ion program and is a basic motivation of NA60.

1.2 Vector meson resonances

The CERES experiment has observed that the yield of low mass e^+e^- pairs measured in p-Be and p-Au collisions is properly described by the expected “cocktail” of hadronic decays, while in Pb-Au collisions, on the contrary, the measured yield, in the mass region 0.2–0.7 GeV, exceeds by a factor 2.5 the expected signal⁶. These observations are consistent with the expectation that the properties of vector mesons should change when produced in dense matter. In particular, near the phase transition to the quark-gluon phase, chiral symmetry should be partially restored, making the vector mesons indistinguishable from their chiral partners, thereby inducing changes in their masses and decay widths. The short lifetime of the ρ meson, shorter than the expected lifetime of the dense system produced in the SPS heavy ion collisions, makes it a sensitive probe of medium effects and, in particular, of chiral symmetry restoration.

For a final proof of this explanation, high resolution data, especially of the low mass resonances, are needed. Besides a good mass resolution better statistics are needed compared to the old CERES measurement. NA60 has the very effective dimuon trigger inherited from NA50. This will allow to study the low mass resonances with much higher statistics than CERES.

2 Experimental apparatus

The NA50 experiment⁷ has been using CERN’s highest intensity heavy ion beam (more than 10^7 ions per second) and has a very selective dimuon trigger, quite appropriate to look for rare processes. The NA60 experiment complements the muon spectrometer and zero degree calorimeter already used in NA50 with two state-of-the-art silicon detectors, placed in the target region: a radiation hard beam tracker, consisting of four silicon microstrip detectors placed on the beam and operated at a temperature of 130 K, and a 10-plane silicon pixel tracking telescope, made with radiation tolerant readout pixel chips, placed in a 2.5 T dipole magnetic field. Because of a delay in the delivery of the pixel readout chips, NA60 will do the proton runs with a telescope build with silicon strip detectors. This solution only works in proton induced collisions where the charged particle multiplicity is low enough.

With these two detector systems the interaction vertex can be reconstructed with an accuracy of roughly $10 \mu\text{m}$ (depending on the centrality of the collision). With the additional magnetic field in front of the absorber, an independent measurement of the momentum is available. Together with the knowledge of the angles, this allows us to match the particles before and after the absorber, the most crucial part in the track reconstruction. The vertex telescope allows to measure the vertex offset of single muon tracks, which is important to select muons from D, K and π decays. It also improves the mass resolution of the muon pairs, since the opening angle can be measured before being distorted by the multiple scattering on the way through the absorber. It also allows to reduce slightly the thickness of the muon absorber to improve the acceptance of low momentum muons.

3 Physics performance capability

The physics performance of the new experiment was studied by implementing the whole setup within Geant. The hard probes were generated with PYTHIA, while the soft part was generated by the Genesis generator previously used by NA50 and CERES. For the underlying background the VENUS generator was used.

The simulated data are reconstructed by taking for the muon spectrometer the standard NA50 reconstruction algorithms. For events with two reconstructed muon tracks also the target telescope is analyzed starting with the beam tracker, which gives the transverse coordinates of the interaction point. With this information the event vertex can be reconstructed with the help of all reconstructed tracks in the telescope. Finally the muon tracks can be matched through the absorber and their impact parameter, i.e. the minimum distance between the track and the collision vertex, in the transverse plane, can be measured with good accuracy.

Thanks to this information, NA60 will be able to separately study the production of prompt dimuons and the production of muons originating from the decay of charmed mesons, in p-A and heavy ion collisions. The prompt dimuon analysis will use events where both muons come from (very close to) the interaction vertex. The open charm event sample is composed of those events where both muon tracks have a certain minimum offset with respect to the interaction point and a minimal distance between themselves at z_{vertex} . It should not be difficult to see which of these two event samples is enhanced by a factor of 2 or 3 in nuclear collisions of $N_{\text{part}} \sim 300$. The result of such a simulated analysis in the intermediate mass region can be seen in figure 1.

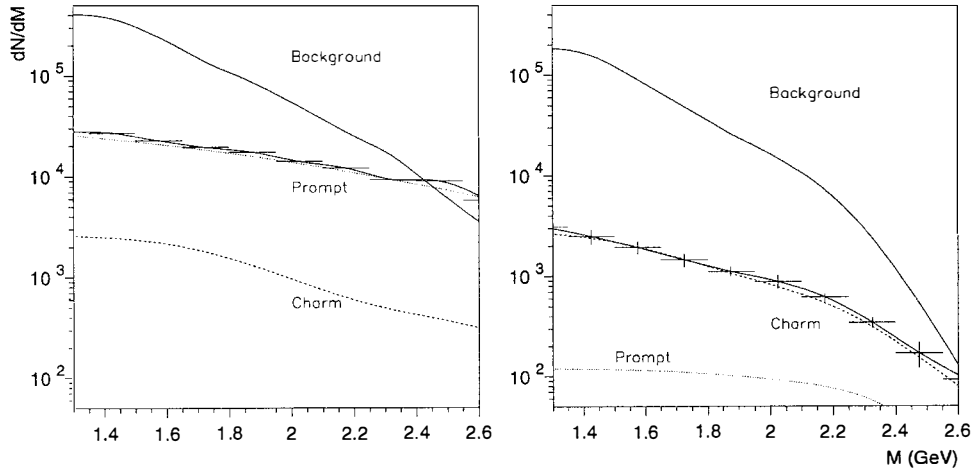


Figure 1: Simulated dimuon mass distributions for the prompt (left) and charm (right) event selections. The background contribution is also shown, including pion/kaon decays and fake matches between the tracks in the muon and in the vertex spectrometers. The error bars in the signal points include the uncertainty from background subtraction.

Besides the simulation, the performance in the low mass region was also tested experimentally with a proton beam. The results of this data analysis can be seen in figure 2. In particular, the improvement in the mass resolution from 70 to 20 MeV at the ω resonance is experimentally confirmed.

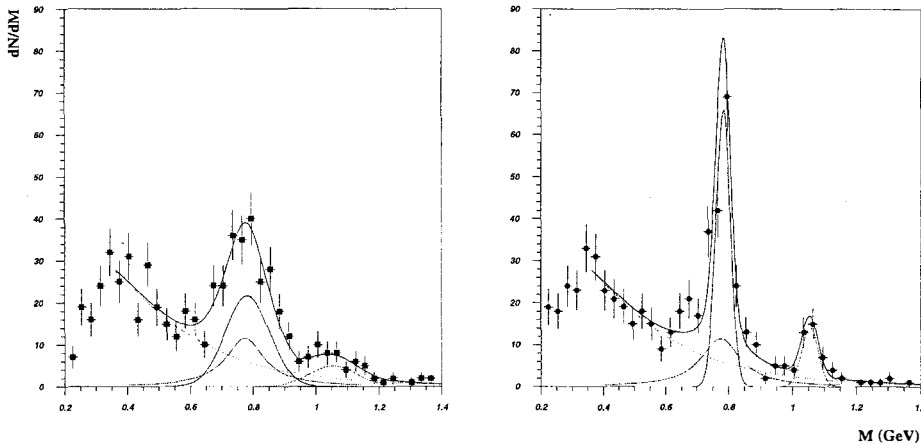


Figure 2: Dimuon mass distributions measured in 1998, in p-Be collisions, before (left) and after (right) using the information of the test pixel telescope. The curves represent the low mass vector meson resonances (ρ , ω and ϕ) on the top of a continuum. They are normalized to the same number of events in both figures. The expected improvement of the mass resolution for the ω resonance from 70 to 20 MeV is experimentally confirmed.

4 Summary

The re-birth of the heavy ion physics program at the CERN SPS, with the extension of NA49 and the approval of the new NA60 experiment, represents an evolution from a broad physics program to a dedicated study of specific signals that already provided very interesting results. The new measurements should give a significant contribution to the understanding of the presently existing results, and considerably help in building a convincing logical case that establishes beyond reasonable doubt the formation (or not) of a deconfined state of matter in heavy ion collisions at the SPS.

References

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