Study of Dimuon Production in Nucleus-Nucleus Interactions at CERN-SPS energies

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ABSTRACT

The NA50 set-up is briefly described. Processes representing different sources of dimuon production are shortly reviewed. Since Pb-Pb data are still preliminary, the recent results on charmonia suppression obtained in S-U interactions, providing a guide line for NA50 experiment, are presented. The J/Ψ and Ψ' yields are compared in p-W, p-U and S-U interactions at 200 GeV/nucleon. Their ratio decreases from proton to sulphur induced reactions. It also decreases in sulphur-induced reactions from peripheral to central collisions.

1 Introduction

The experimental data on muon production in high energy nuclear collisions present a special interest for probing the Quark-Gluon Plasma (QGP) predicted by QCD to occur at sufficiently high energy density. The muons, due to their low interaction cross section with the nuclear medium, leave the hadronic matter without further interactions, carrying out information about the conditions in the matter at the time of their emission.

The main goal of the NA50 experiment is the study of those signals, accessible in dimuon production and theoretically correlated with the transition of the hadronic matter into a QGP, using the new condition offered by lead beam, available at CERN-SPS. Thus NA50 is continuing in Pb-Pb interactions the studies performed by NA38 in O and S induced reactions on different target nuclei.

The Pb-Pb collisions - collisions between really heavy ions - offer better conditions for thermalization, i.e. a larger volume of interactions, a longer lived excitation region and higher energy density, at least locally, in the core of central interactions. These better conditions justify the present expectations for a better understanding of the nature of the dense matter formed in high energy nuclear collisions.

This talk describes shortly the NA50 experimental set-up, presents a short review of the processes representing the different sources of dimuon emission and, finally, shows some results on charmonium suppression obtained in p and S induced reactions since the Pb-Pb data are still preliminary.

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2 The NA50 set-up

The set-up is based on NA38 apparatus upgraded to stand for: a) a higher trigger rate and b) a higher radiation level.

For a more complete information about the global features of the interactions in which dimuons are produced, two new sub-detectors were introduced: a) a multiplicity detector (MD) and b) a Zero Degree Calorimeter (ZDC).

The MD[1] is made of two planes of silicon strip detectors. Each plane, extending from a inner radius of .36 cm to an outer radius of 9.4 cm, is subdivided in smaller sub-detectors.The total number of channels is 11520 grouped in 216 sub-detectors. The main characteristics of the MD are: a) an acceptance of $1.6 < \eta < 4$ for all sub-targets, b) a granularity of $\Delta\eta = .02$ and $\Delta\varphi = 10^0$, c) a cell occupancy of at most 30% for central collisions and d) a resolution of $\approx 5\%$.

The ZDC measures the energy deposited by the projectile spectator fragments. It measures the Čerenkov light produced in silica optical fibers embedded in tantalum. The active volume is $5 \times 5 \times 65$ cm^3 with a fiber to tantalum ratio equal to 1/17. It is highly radiation resistant and very fast. For lead ions the resolution is equal to 5%, while for protons at $p = 205$ GeV/c is 30%.

Thus the NA50 detector is mainly composed of a muon spectrometer, a Zero Degree Calorimeter, an Electromagnetic Calorimeter, a Multiplicity Detector, an active target and some beam counters.

The muon spectrometer consists of a beam dump surrounded by a hadron absorber, an air-core toroidal magnet of hexagonal symmetry, two sets of 4 multiwire proportional chambers and six hodoscopes of plastic scintillator, four of which provide the trigger [2]. The

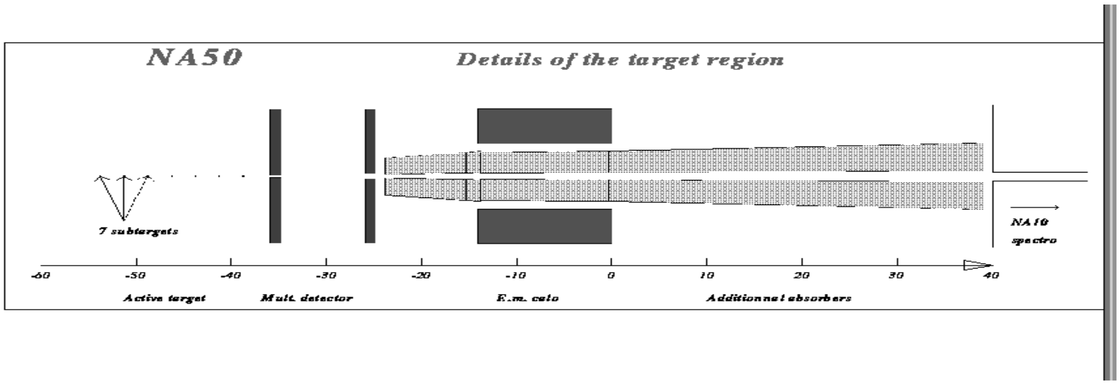

Figure 1: Overview of the target region.

spectometer detects dimuons with a mass in the range $.5 < M_{\mu\mu} < 7\ GeV/c^2$ and a rapidity in the interval $2.7 < \eta < 3.9$. The target contains 7 sub-targets, each .5 - 1 mm thick, placed at 2.5 cm intervals along the beam axis. Each sub-target is followed 1.5 cm downstream by two quartz blades, located slightly off the beam axis which provides the needed identification of the interaction vertex. (Fig.1)

3 Processes Involved in Dimuon Production

In the present short description of the different sources of dimuon production, the correlation between the dimuon mass and the time development of the formed system in nucleus-nucleus collision is followed.

The region of high masses ($M > 4\ GeV/c^2$) is the region of Drell-Yan dimuon production - hard annihilation of primary $q\bar{q}$ pairs into muon pairs via a virtual photon intermediate state. Drell-Yan dimuons are carrying the earliest information about the system since they are emmited at the pre-equilibrium stage. They are not affected by the subsequent development of the interaction region and are used as reference for other processes.

In the region of J/Ψ and Ψ' ($3 < M < 4\ GeV/c^2$), the production of $c\bar{c}$ pairs (dominantly by primary gluon fusion) is taking place at a very early time in the interaction. The $c\bar{c}$ pairs will bind to form charmonia or will produce charm mesons. The binding is affected by the presence of the deconfinement (QGP). Matsui and Satz[3] predicted a supression of J/Ψ relative to Drell-Yan pairs in heavy ion collisions via Debye colour screening in QGP and this suppression was observed by NA38 [4]. The J/Ψ suppression was seen to be stronger at low transverse momenta as $c\bar{c}$ pairs, with high $p_\perp$, escape from the plasma before the resonance formation. The suppression is expected to be stronger for Ψ' than J/Ψ due to its larger radius and easier Debye screening.

In the intermediate region ($1.5 < M < 3\ GeV/c^2$), Drell-Yan pair production is still dominant but charm semi-leptonic decays have a significant contribution. Thermal dimuons (soft annihilation of the constituents of the medium), if observable, will provide information about the temperature of the medium from which they are emmited[5].

The low mass region ($.5 < M < 1.5\ GeV/c^2$) is the region of ρ, ω, φ resonances. The φ meson gives access to the strangeness content of the matter formed in heavy ion collisions. NA38 has observed a clear increase of the ratio $\varphi/(\rho+\omega)$ with increasing centrality in S - U interactions and an increase by a factor 3 between p -W and S - U central collisions[6].

Stangeness enhancement, previously predicted as a signature of QGP, is now considered as an indication of a dense hadron gas in equilibrium. Rescattering among incident nucleons (responsible for primary strangeness production) and rescattering among secondaries and nucleons and among secondary themselves (responsable for secondary strangeness production) show a well developed tendency of the hadron gas towards chemical equilibrium.

4 Results on J/Ψ and Ψ' Production

Since the Pb-Pb data are still preliminary, recent results [7] on charmonium suppression, obtained by NA38, are shortly reviewed. These results represent a valuable reference for the forthcoming Pb-Pb studies and are very important for the interpretation - QGP [3, 8] versus absorption[9] - of the previously observed J/Ψ suppression.

The ratio between Ψ' and J/Ψ yields in S-U interactions was estimated from the opposite-sign muon pair spectrum according to the following procedure. The like-sign muon pairs are used to get the "combinatorial background" and the continuum above 2.9 GeV/c^2 is assumed to be purely Drell-Yan and is calculated using the Pythia event generator with GRV LO structure functions. The mass range of the distribution, presenting interest for the charmonia suppression, $2.9 < M < 7.\ GeV/c^2$, is fitted with three functions describing the shape of the J/Ψ, Ψ' and Drell-Yan obtained from the simulation of the detector response. For the proton induced reactions the fitting procedure is similar.

The S-U data were divided into four equipopulated bins of the neutral transverse energy E_T^0. The fitting procedure was applied to each bin of E_T^0 in order to obtain information about the ratio $\Psi'/(J/\Psi)$ as a function of the collision centrality. The ratio $\Psi'/\Psi = B'_{\mu\mu}\sigma(\Psi')/B_{\mu\mu}\sigma(J/\Psi)$, where $B'_{\mu\mu}$ and $B_{\mu\mu}$ are the branching ratios of the Ψ' and J/Ψ into two muons, is ploted as a function of E_T^0, (Fig 2). It can be seen the decrease of this ratio by a factor 2 from p-U to S-U interactions and the decrease by a factor 1.6 from peripheral to most central S-U interactions. The energy

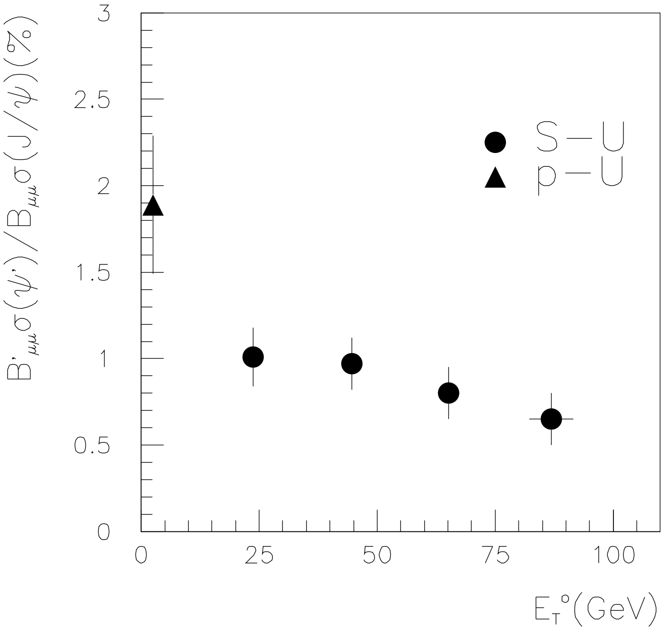

Figure 2. The ratio $B'_{\mu\mu}\sigma(\Psi')/B_{\mu\mu}\sigma(J/\psi)$ as a function of the neutral transverse energy E_T^0.

density is defined following Bjorken estimate[10] from the neutral transverse energy and the transverse area of the volume in which the energy is deposited, given by the the geometrical model of hard spheres.

In Fig.3 the ratio Ψ'/Ψ as a function of the energy density ϵ is represented. The decrease of Ψ'/Ψ with the increase of the energy density agrees with the general trend, as predicted by QGP calculation[11]. However the decrease of Ψ'/Ψ is also in agreement with the predictions given by the absorption models.

The ratio Ψ'/Ψ plotted as a function of the mass number of the target (A), for different p-A collisions[12] is presented in Fig.4. It can be seen that it does not depend on A and has the same value as in pp interactions. The ratio Ψ'/Ψ for p-A interactions, as well as for the S-U interactions binned in E_T^0, is plotted against L,

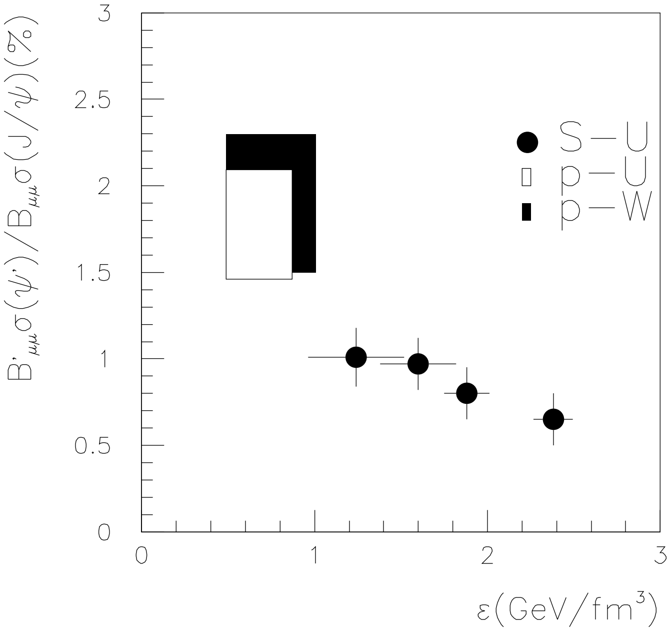

Figure 3. The ratio $B_{\mu\mu}\sigma(\Psi')/B_{\mu\mu}\sigma(J/\Psi)$ as a function of collision energy density - ϵ.

the average path length in nucleus [13]. A different behaviour of the ratio Ψ'/Ψ in p-A and A-A interactions is clearly seen (Fig.5), in contrast with the behaviour of the ratio J/Ψ/continuum for p-A and A-A interactions, where the dependence on L is well described by the same exponential decrease and was interpreted as an important argument towards more conventional mechanisms [13].

Satz[14] explained the observation of the same suppression for J/Ψ and Ψ' in p-A interactions by the formation of J/Ψ and Ψ', as fully bound states, well outside the nucleus. The initially formed states $c\bar{c}$ are in general coloured and the fast charmonia traverse the nucleus while are still in color octet states. The color evaporation occurs well outside the nucleus when they become fully formed resonances or open charm mesons. This would be a possible explanation for the fact that the two resonances, J/Ψ and Ψ', which differ in size by a factor 4, are affected by the medium in the same way.

Thus in p-A interactions it is possible to study the passage of a colour charge through the confined medium, and it is expected that with a better understanding of this mechanism, it will be possible to distinguish in A-A collisions between confined and deconfined media.

For the study of the passage of J/Ψ and Ψ' through confined matter, a new experiment was proposed - lead beam incident on a hydrogen (or deuterium) target - where slow charmonia in nucleus rest frame can be studied. Slow charmonia become fully formed resonances within a hadronic volume around $c\bar{c}$ formation point and thus their study in A-p interaction will give information about the passage of J/Ψ and Ψ' through confined matter.

Thus new data on lead beam incident on lead-target, as well as on a hydrogen target, are expected, in the near future, to contribute to a better understanding of the effects of a confined and deconfined media on J/Ψ and Ψ' production.

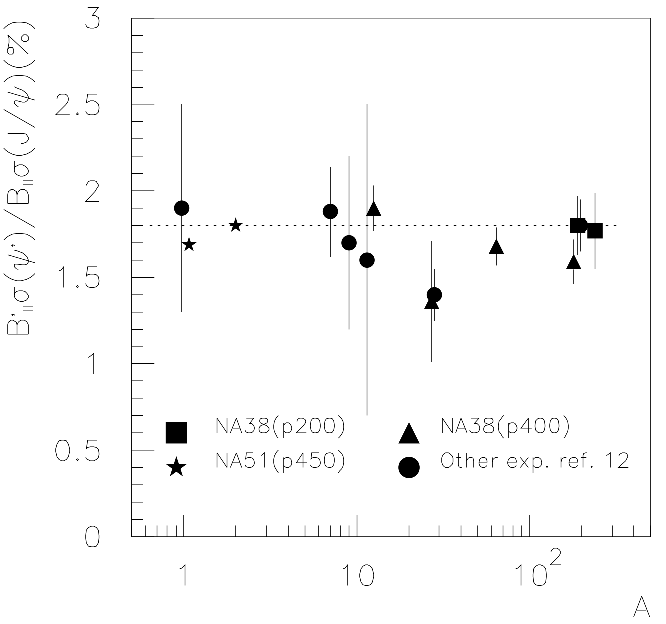

Figure 4. The ratio $B_{ll}\sigma(\Psi')/B_{ll}\sigma(J/\Psi)$ as a function of A (ll for lepton pairs - muon or electron pairs). For p-A collisions at projectile energies different from 200 GeV, the ratio is corrected for the $\sqrt{s}$ dependence of the cross-sections.

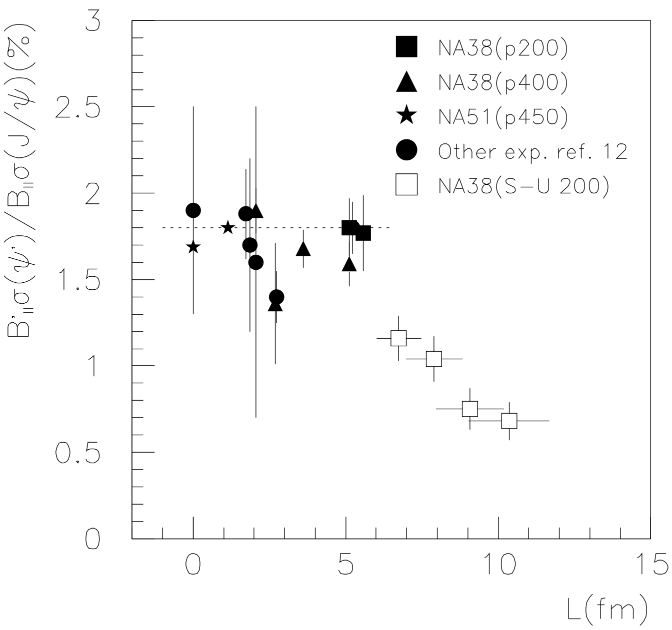

Figure 5. The ratio $B_{ll}\sigma(\Psi')/B_{ll}\sigma(J/\Psi)$ as a function of L (ll for lepton pairs - muon or electron pairs). For p-A collisions at projectile energies different from 200 GeV, the ratio was corrected for the $\sqrt{s}$ dependence of the cross sections.

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