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Study of dimuon and heavy-flavour production in proton-nucleus and heavy-ion collisions

The NA60 Collaboration

The NA60 experiment was motivated by three specific experimental observations made by previous SPS experiments (NA38, NA50 and CERES):

1. The yield of intermediate mass dimuons seen in heavy-ion collisions (S-U and Pb-Pb) significantly exceeds the expected contributions from Drell-Yan dimuons and D meson decays, while the proton-nucleus data is perfectly well described.

2. The low mass dielectron data collected in heavy-ion collisions (S-Au and Pb-Au) exceeds the expected cocktail of light meson decays, while the p-Be data is very well reproduced.

3. The J/ψ and ψ' production yields are suppressed in heavy-ion collisions with respect to the normal nuclear absorption pattern determined by proton-nucleus data.

A sizeable sample of Indium-Indium events was collected in 2003. More than 1 million low mass signal dimuons should remain after muon track matching, with a mass resolution around 20 MeV at the ω and ϕ peaks, a signal to background ratio close to unity, and a broad coverage of transverse momentum and collision centrality, estimated by the associated charged particle multiplicity and by the forward energy deposited in the ZDC. Such an event sample should allow us to clarify the origin of the low mass dilepton excess. To investigate if the intermediate mass dimuon excess signals the production of thermal dimuons from a quark-gluon plasma, and to measure the open charm yield in nucleus-nucleus collisions, we will use the measurement of secondary vertices with around 50 μm precision, to separate prompt dimuons from D meson decays. To identify the physics variable driving the J/ψ suppression, we will compare the centrality dependence of the J/ψ production yield measured in Indium collisions with the corresponding pattern previously determined with Lead collisions, at the same collision energy. Reference data will be collected with proton beams in 2004, to define a reference baseline with respect to which we can extract any "anomalous behaviour" specific to heavy-ion collisions.

A detailed proposal for further studies should be based on the outcome of the analysis of the data collected in 2003 and 2004. The following lines correspond to what can be said at this moment, before those results are available.

In order to complete its "heavy-ion" physics program, NA60 should study prompt dimuon and open charm production in the heaviest and most energetic nuclear collision systems available at the SPS: Pb-Pb at 158 GeV per nucleon. This run was planned for year 2002 but was cancelled in view of delays in the availability of the silicon pixel assemblies. Such an event sample would allow us to study several important physics issues:

- The charm production yield and its centrality dependence, the ideal reference for the studies of J/ψ suppression, since both processes are mostly due to gluon fusion, thereby canceling out uncertainties related to initial state effects.
- The temperature of the partonic system produced in those collisions, by studying prompt dimuon radiation in excess of the standard Drell-Yan process.
- The J/ψ suppression pattern up to the highest energy densities that can be produced at the SPS, with a significantly improved detector system with respect to the one used by NA50.
- The restoration of chiral symmetry by measuring the properties of the ρ meson when produced in the heaviest nuclear collisions available; and the production yield and p_{T} distribution of the ϕ, both through $\mu^+\mu^-$ and $\mathrm{K}^+\mathrm{K}^-$ decays.

We are also very interested in studying hadro-production of charmonium states, in proton-nucleus interactions. In particular, we would like to measure the *differential* nuclear dependence of the J/ψ and ψ' mesons, as a function of p_{T} and x_{F}. A good scan as a function of x_{F} (or rapidity) is possible by displacing the components of the dimuon spectrometer (hodoscopes, chambers and magnet) with respect to the target position. The impact of these measurements would vastly increase if done with protons of two different energies, 400 and 158 GeV, so that the formation of the bound charmonium states from the produced $c\bar{c}$ pair can also be studied as a function of the collision energy. The comparison with existing data from Fermilab (E866) and DESY (HERA-B), at 800 and 920 GeV, also available over extended ranges of x_{F}, should enable us to vastly improve our understanding of quarkonium production. The extension of these measurements to the negative x_{F} domain can be accomplished by simply studying, with the same detector, collisions of incident Pb ions on a light nuclear target, such as Be. The measured charmonium mesons would then be slow in the rest frame of the nuclear beam and should be fully formed physical states while traversing the nucleus, contrary to the states measured at forward x_{F}, which are expected to cross most of the nucleus as a pre-resonant $c\bar{c}$ pair. These measurements should also contribute to a better definition of the parton distribution functions and their nuclear modifications, in particular for the gluons.

Finally, we would like to express a strong interest in pursuing the studies of the $\mathrm{D}^0 \to \mu^+\mu^-$ rare charm decay, which we will start as a by-product with the 2003 and 2004 event samples. We explained the interest of such measurements in our SPSC memorandum of August 2003, which should be consulted for further information. Detailed studies are on-going and indicate that a dedicated data taking period for this study, with a high-intensity proton beam of 400 GeV, would lead to a very significant improvement on the presently available upper limit, 2.5×10^{-6}, set by CDF. Such a run would also allow us to measure the B meson absolute production cross-section.