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The NA60 experiment. First results and prospects

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The NA60 experiment studies the production of open charm and prompt dimuons in proton-nucleus and nucleus-nucleus collisions at the CERN SPS. It aims to examine various possible signatures of the transition from hadronic to deconfined partonic matter, e.g., anomalous charmonium suppression, dimuons from thermal radiation, and modifications of vector meson properties. With its radiation hard silicon detectors, NA60 can access the kinematics of charged particles at the vertex level, and identify the muons among them by matching them with the track segments of the muon spectrometer. The vertexing precision makes it possible to measure the offset of muon tracks of D meson decays, distinguishing them from prompt dimuons. The collision centrality is measured by the zero-degree calorimeter. After two test runs, the silicon vertex spectrometer is now in the final phase of production to be ready for the In-In run in October 2003.

1 Physics goals

Experiments at the SPS have studied the properties of hot and dense matter since the start of CERN's heavy ion program in 1986. One line of experiments has focused its attention on dimuon production. The NA38 and NA50 experiments studied high mass dimuons and charmonia. These are produced in hard processes and are thus the cleanest source of information emerging from the early stage of the system's development, unaffected by later hadronization. NA60 continues this line of pursuit with significantly enhanced capabilities owing to the latest advances in detector technology. Using novel, radiation tolerant silicon detectors, NA60 can address the most intriguing questions raised by its predecessors.

The NA50 experiment found that the charmonium yield is much lower in central Pb-Pb collisions than predicted by the nuclear absorption model which describes well the spectrum in lighter and/or more peripheral collision systems [1]. Among the observations made in search of the formation of quark-gluon plasma, this sudden, sharp deviation bears the closest resemblance to the threshold-like phenomena associated with phase transitions. It is unclear

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however whether it is the J/ψ that is suppressed, or the heavier, more loosely bound χ_c, whose radiative decay produces about one third of all the J/ψ's. NA60 will study the absorption of χ_c in nuclear matter using proton-nucleus (Be, In, Pb) collisions. Also, the anomalous suppression sets in at about 2 GeV/fm^3, an energy density significantly higher than the lattice QCD prediction of 0.7 GeV/fm^3 for the phase transition. This may indicate that energy density is not the relevant parameter in this phenomenon. An alternative model does not imply thermalization, and interprets deconfinement as cluster percolation, with participating parton density as the critical scale [2]. However, as the anomalous suppression has so far been observed in Pb-Pb collisions only, more data are needed to test any model's validity. NA60 will study anomalous suppression in the lighter In-In colliding system in order identify the variable that governs its onset.

Between the ϕ and J/ψ resonances, the dimuon spectrum in p-A collisions can be well described by the sum of Drell-Yan dileptons and dimuons coming from D meson decays. S-U and Pb-Pb collisions however show an excess in this intermediate mass region [3]. This excess can be accounted for by assuming a threefold enhancement of open charm yield [3], or the production of thermal dimuons in a quark-gluon plasma phase [4]. The latter would be the most direct evidence of the formation of a thermalized deconfined medium. Equipped with state-of-the-art silicon detectors, NA60 will be able to distinguish these two sources by measuring the offset of the muon tracks originating from the decay of the D mesons, which travel typically several hundred of microns before decaying.

In studying the dilepton spectra in proton-nucleus collisions, the CERES collaboration could describe the observed yield in the 0.2-0.7 GeV mass region by a "cocktail" of known hadronic decays. In Pb-Au collisions however the measured yield exceeded the expected one by a factor of 2.5 [5]. This low mass dilepton excess may be an indication of partial chiral symmetry restoration near the quark-gluon plasma phase transition. With its excellent mass resolution and its acceptance extended well below that of previous dimuon experiments, NA60 is also well suited to study possible modifications of the shape of the ρ and ω peaks in the hot and dense medium created in high energy nuclear collisions.

2 The detector

NA60 complements the muon spectrometer and zero degree calorimeter previously used by the NA50 experiment with silicon detectors in the vertex region (Fig. 1).

The incoming beam particles are tracked by a cryogenic silicon microstrip detector [6]. Two pairs of orthogonal microstrip sensors placed 10 cm and 30 cm upstream of the target provide two space points of the individual beam particles with a precision of 20 μm in the transverse plane. The signal from the back plane of the sensors times the passage of the beam particles with a resolution of one nanosecond. The beam tracker is operated at 130 K, dramatically increasing the sensors' radiation hardness. In a test conducted in 2000, the sensors withstood a three week long exposure to a total of 5×10^{14} ions/cm^2 of the 158 GeV /nucleon Pb beam with significantly reduced, but still well distinguishable, signals.

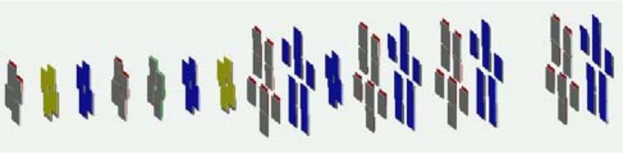

Figure 1. The complete vertex telescope will consist of eight 4-chip, and eight 8-chip modules.

The charged particles are tracked by the silicon vertex telescope placed in a 2.5 T homogeneous magnetic field. The complete vertex telescope will be made up of 96 silicon pixel chips arranged in eight 4-chip modules and eight 8-chip modules (Fig. 1). Each of the 4-chip modules in the upstream half of the telescope covers most of the acceptance of the muon spectrometer, whereas it takes one pair of 8-chip modules in the downstream half to do so. The chips are glued onto an Al_2O_3 or BeO hybrid carrying a multilayer bus structure. The hybrid in turn is glued onto a PCB, over a large hole. The module is cooled by cold water circulating in a copper tube attached to the back of the hybrid. All connections from the chips to the hybrid, and the signal connections from the hybrid to the PCB are made by wire-bonding. The pixel chip's active area is a 32×256 matrix of $425 \times 50\,\mu\mathrm{m}^2$ pixels. The 300 μm thick pixel sensor chip is bump-bonded to the read-out electronics chip, which has a matrix of pixels congruent to that of the sensor chip. Each pixel cell of this matrix contains an amplifier, a shaper, a programmable discriminator and a programmable digital delay line to match the trigger latency of the experiment. The chip is operated at 10 MHz and read out in 25.6 μs over 32 parallel data lines. The chips on the bus are read out sequentially. The programming and readout of the chips are controlled by PCI cards in Linux boxes [7]. The chips were designed for the Alice and LHCb experiments using 0.25-micron CMOS technology and radiation hard architecture [8]. The readout chips have been shown to be radiation tolerant up to at least 12 Mrad [9].

The beam tracker and the vertex telescope can measure the primary vertex position with 200 μm precision in the coordinate parallel to the beam, and with better than 20 μm perpendicular to it. Muons are selected from the vertex telescope's tracks by matching their coordinates and momenta with those of the muon spectrometer's tracks. The identified muon tracks' displacement from the primary vertex is used to distinguish D-meson decays from prompt decays.

When running with ion beams, the zero-degree calorimeter measures the energy of the beam remnants. Comparing it with the total energy of the beam particle reveals the number of nucleons participating in the interaction, which gives a measure of the centrality of the collision.

The muon spectrometer is placed behind a hadron absorber and covers $35 < \theta < 120$ mrad in polar angle. It consists of 8 multiwire proportional chambers, 4 upstream, and 4 downstream of a toroidal magnet, and six scintillator trigger hodoscopes.

3 First results

NA60 has had two test runs, one with a 400 GeV proton beam and another with 20 GeV/nucleon and 30 GeV/nucleon Pb beams.

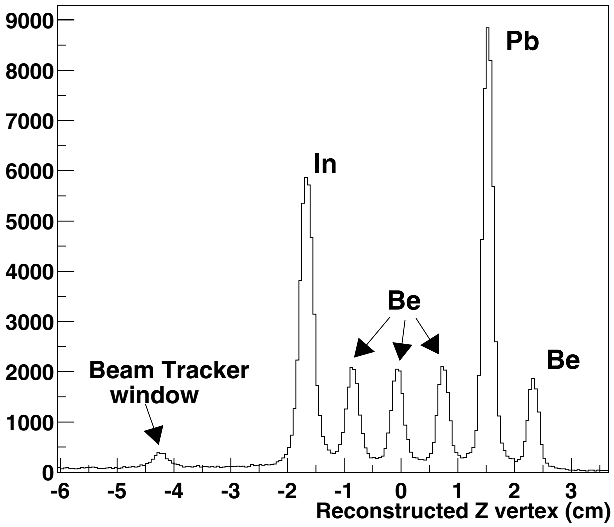

Figure 2. Distribution of the reconstructed vertices in the direction along the beam in proton-nucleus collisions.

In the proton run in June 2002, the first 4-chip pixel module and its readout chain were tested under real experimental conditions. The relatively low charged particle multiplicity of the proton-nucleus collisions allowed the rest of the vertex spectrometer to be made up of silicon microstrip detectors. Figure 2 shows the distribution of the z coordinate (along the beam) of the reconstructed vertices. With 900 μm resolution the six 2 mm thick targets with 8 mm space between neighbors are well separated, allowing the simultaneous study of indium, berillium and lead targets. The lead target also served as a converter of photons from the radiative decay of χ_c. Fits to the ω and ϕ peaks of the reconstructed dimuons' mass distribution (Fig. 3) give a resolution of 25 MeV and 30 MeV, respectively. The extended acceptance for low mass dimuons down to very low transverse momenta is illustrated in Figure 4.

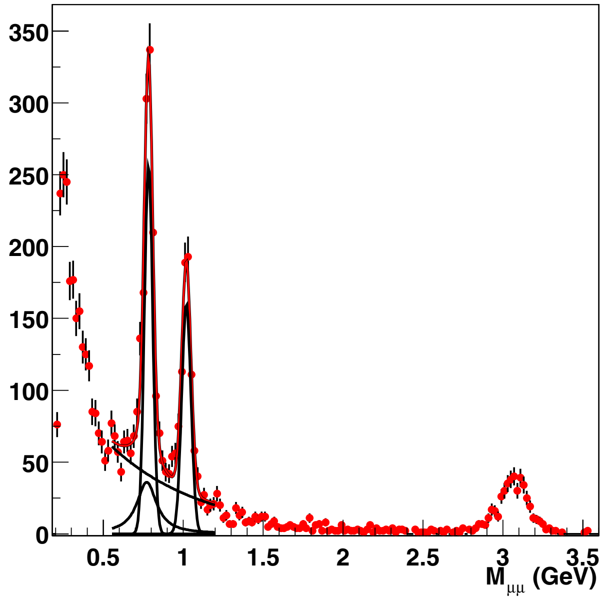

Figure 3. The mass distribution of reconstructed dimuons in proton-nucleus collisions.

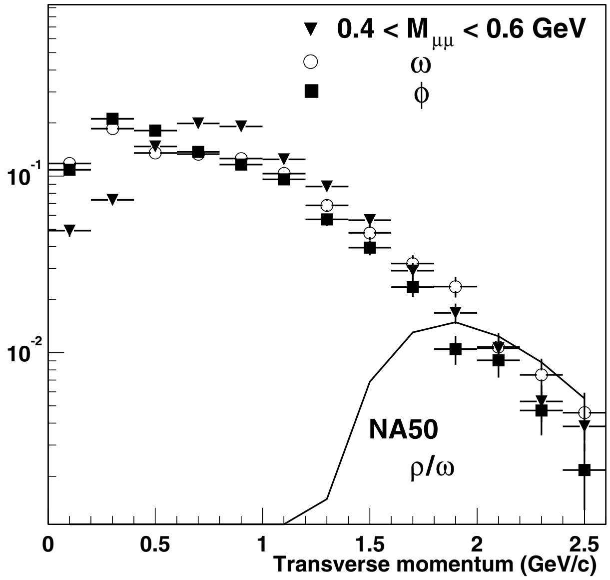

Figure 4. The measured transverse momentum spectra in various mass windows extend well below that of NA50 at the ρ/ω peak.

In the Pb test run in October 2002, three 4-chip pixel modules were tested. As three points are insufficient for momentum measurement, the magnet was switched off and the modules were moved close to the target for better vertexing precision and in order to improve their acceptance at mid-rapidity, which is at 2.08 for the 30 GeV/nucleon case. The three Pb targets are resolved with better than 200 μm precision in the direction parallel to the beam (Fig. 5). To assess the resolution in the transverse direction, the x coordinate measured by the three pixel modules is compared with that measured by the beam tracker, which has a resolution of 20 μm. From the correlation a vertex resolution of 20 μm is inferred for the pixel telescope, in spite of its having only three modules.

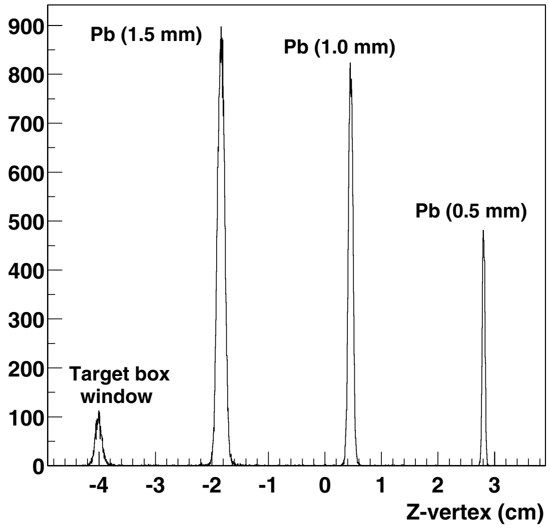

Figure 5. Distribution of the reconstructed vertices in the direction along the beam in Pb-Pb collisions.

As a by-product of the Pb test run, the data collected at 30 GeV/nucleon beam energy have been used to measure the charged particle multiplicity with a simple cluster counting procedure. The counts in each pseudo-rapidity bin have been corrected for the acceptance. The contribution from secondary particles has been estimated by generating Monte Carlo events with UrQMD 1.2 and tracking the particles with GEANT 3.21. The δ-ray contribution from the Pb beam ions has also been estimated by GEANT 3.21 simulation. The events have been divided into three centrality classes. The centrality of the collisions has been derived from the zero-degree calorimeter information, using the Glauber model. The systematic error on the multiplicities is estimated to be 11 %. The charged particle multiplicies as a function of the pseudo-rapidity are plotted and fitted with a gaussian for each centrality class in Figure 6. The fit results are summarized in Table 1.

As the zero-degree calorimeter was designed to work with beam particles of much higher energy, at 30 GeV/nucleon it approaches its limit of optimal operation, and at 20 GeV/nucleon it becomes too inefficient to be used for the definition of centrality classes.

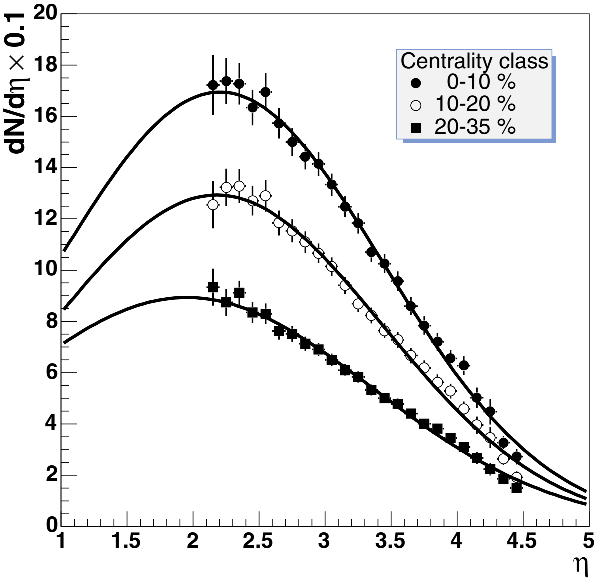

Figure 6. Charge particle multipliciy vs. pseudo-rapidity in three centrality classes of the 30 GeV/nucleon Pb-Pb collisions. The errors shown are purely statistical.

Table 1. The results of the gaussian fits to the charge particle pseudo-rapidity density in the three collision centrality classes. Class 1 contains the most central 10 % of events, class 2 the most central 10 % of the rest, and so on.

Class	Bin	$(dN/d\eta)_{max}$	η_{max}	σ
1	0-10%	166 ± 5	2.2 ± 0.1	1.25 ± 0.05
2	10-20%	128 ± 7	2.2 ± 0.1	1.27 ± 0.06
3	20-35%	90 ± 3	1.9 ± 0.2	1.42 ± 0.08

4 Prospects

The test run results have proved the validity of the detector concept. The dimuon invariant mass can be measured with 25 MeV resolution at the ω peak by combining the information from the muon spectrometer and the vertex telescope. The vertexing precision permits the use of a multi-target system and makes the identification of D meson decays possible. The extended low mass acceptance of the detector has broadened the experiment's range of physics topics. The silicon pixel vertex spectrometer is now in the final phase of production to be ready for the In-In run in October 2003. In 2004 the experiment will collect data of proton-nucleus collisions. NA60 is looking forward to exciting new physics results.

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