Charged particle multiplicity measurements in NA60

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Abstract. The NA60 experiment at the CERN SPS studies dimuon production in nucleus-nucleus and proton-nucleus collisions. One of the main detectors in the apparatus is the silicon pixel vertex telescope, which tracks charged particles in the target region. This detector complements the information from the muon spectrometer, improving the dimuon mass resolution and signal-to-noise ratio of the experiment, overcoming the main limitations of its predecessors.

The silicon vertex telescope also provides the experiment with the capability of measuring charged particle multiplicities. In this paper we briefly describe the experiment and some preliminary results on charged particle multiplicities for two different colliding systems at different incident beam energies (Pb-Pb at 30 AGeV and In-In at 158 AGeV).
1. Introduction

NA60 is a fixed-target experiment that mainly studies dimuon production in proton-nucleus and nucleus-nucleus collisions at the CERN SPS [1, 3, 4]. Its detector complements the muon spectrometer and zero-degree calorimeter previously used in the NA50 [2] experiment with two state-of-the-art silicon detectors in the vertex region: a cryogenic silicon beam tracker and a silicon tracking telescope.

The main limiting factor in previous experiments came from the hadron absorber of the muon spectrometer. It is needed to ensure that only muons can trigger the experiment but, because of multiple scattering and energy loss, it limits the dimuon mass resolution and renders accurate vertexing impossible. To overcome these limitations, NA60 needs a vertex tracker compatible with the high multiplicity environment of heavy-ion collisions and the high luminosities necessary to achieve reasonable dimuon statistics. A tracker to be used in such an environment must be both highly granular and radiation tolerant, a combination which only recently has become available with the development of radiation tolerant silicon pixel detectors. Tracking in the vertex region significantly improves the mass resolution and the signal-to-noise ratio, the former by matching muon tracks before and after the absorber and the latter by rejecting muons from $\pi$ and $K$ decays, the main source of background. For the first time in a heavy-ion experiment, it has become possible to distinguish between muon pairs originating from the simultaneous semi-leptonic decays of $D$ mesons and dimuons coming from the interaction vertex, by measuring the offset of the tracks with respect to the interaction point.

In addition to the main physics program, the new vertex detectors provide NA60 with the capability of measuring charged particle multiplicities. In this paper results on charged particle multiplicity for two colliding systems at different energies are presented.

2. The NA60 Experimental Apparatus

The NA60 experimental apparatus is depicted in figure 1. It is composed of four main detectors: a muon spectrometer, a zero-degree calorimeter, a silicon beam tracker and a silicon pixel telescope.

The muon spectrometer tracks the muons produced in the collision. It is separated from the vertex region by a hadron absorber, ensuring that only muons can reach the spectrometer. It is also used to produce a very selective “dimuon trigger”, which allows to collect large samples of rare events. The muon spectrometer was not used for the analysis described in this paper, as it is aimed at measuring total charged particle multiplicities. The Zero-Degree Calorimeter (ZDC) is a quartz-fiber “spaghetti” calorimeter which measures the centrality of heavy ion collisions by detecting the energy of non-interacting fragments. The beam tracker is a cryogenic silicon strip...
detector, used to track incoming ions before they hit the target. It provides two tracking points, being composed of four strip sensors arranged in two planes. It is operated at 130 K to profit from the so-called Lazarus effect [5] and can stand huge doses of radiation [6]. This detector constrains the interaction point and provides a valuable tool for offline analysis. The zero-degree calorimeter and the beam tracker also provide two minimum bias triggers, which were used for this analysis. The former is a signal produced each time the energy deposited in the calorimeter is within a certain limit, thus rejecting noise and non-interaction events. The latter is a signal produced by the backplane of the beam tracker sensors each time an ion crosses it. The silicon pixel telescope is used to track charged particles in the vertex region. It was the main tool for the analysis work presented in this paper and is described in full detail in the next section.

3. Silicon pixel vertex telescope
The silicon pixel telescope [10] consists of several tracking planes made from assemblies of a silicon sensor bump-bonded to a radiation tolerant readout chip. The actual layout of the telescope and the type of silicon detectors used has changed in the data taking periods, following the particular physics needs of a given run and the availability of silicon detectors. During proton runs, microstrip sensors were also used.

The detectors used during data-taking periods of interest for this paper were based on a readout chip developed for the ALICE and LHCb experiments at CERN [7]. They have a $256 \times 32$ matrix of $50 \times 425 \, \mu \text{m}^2$ cells covering a sensitive area of $12.8 \times 13.6 \, \text{mm}^2$. The assemblies are mounted on a ceramic hybrid. The readout chip is manufactured in a 0.25 $\mu \text{m}$ CMOS technology and designed with special techniques in order to increase its radiation tolerance. It has been shown to remain fully functional after an absorbed dose of about 12 Mrad [8].

The telescope is made of “small” and “large” tracking stations, because at different distances from the target, different areas are needed to cover the angular acceptance of the muon spectrometer. Planes can be composed of either four or eight assemblies, two eight-assemblies plane are needed to form a “large” station, while one four-assemblies plane represents a “small” station. Each plane has a material budget of about 3$\%$ $X_0$, mainly due to the silicon of the sensor (300 $\mu \text{m}$) and readout chip (750 $\mu \text{m}$) and to the gold used in the ground and power planes of the hybrid (effective thickness $\sim 30 \, \mu \text{m}$). The vertex telescope is placed inside a 2.5 T dipole field in order to measure particle momenta. The actual setups used during the data taking periods analyzed in this paper are described in later sections.

4. Multiplicity measurements
The charged particle multiplicity was measured as a function of pseudorapidity and centrality, for data collected in two periods, with different colliding systems and energies:

- October 2002: Pb-Pb collisions at an incident beam energy of 30 AGeV
- October-November 2003: In-In collisions at an incident beam energy of 158 AGeV

The experimental setup, and hence the analysis approach during the two data taking periods, were different and will be discussed independently.

Monte Carlo simulations were used to estimate the detector response and correct the experimental data. Events were generated using UrQMD 1.2 [11] and VENUS 4.12 [12], while GEANT 3.21 [13] was used to track the particles in the experimental setup.

4.1. Pb-Pb collisions at 30 AGeV
The October 2002 low energy run was essentially a test run for the first three pixel planes. This small telescope was used to measure charged particle multiplicity.
Figure 2. Display of a reconstructed event in the beam tracker and pixel detector (2002 lead run).

Figure 3. Z-vertex distribution determined by the vertex telescope in Pb-Pb.

The experimental setup was composed of the telescope, the beam tracker and the ZDC. The trigger signal was provided by the zero-degree calorimeter. Three lead targets of different thickness (1.5 mm, 1.0 mm and 0.5 mm) were installed at different positions along the beam line. The pixel planes were put as close as possible to the target in order to cover a rapidity window closer to mid-rapidity ($y = 2.08$, $\eta = 2.14$ at $30 \text{ AGeV}$). Figure 2 shows the display of an event reconstructed in the beam tracker and in the pixel detector. Data were collected without the vertex magnetic field, since only three tracking points were available.

Despite the fact that only three pixel planes were available, the interaction vertex was reconstructed with a resolution of $\sim 200 \mu\text{m}$ in the longitudinal coordinate and $\sim 20 \mu\text{m}$ in the transverse coordinates. The resolution on the longitudinal coordinate can be estimated from the Z-vertex distribution (figure 3). The resolution in the transverse plane is extracted from the correlation between the transverse coordinates of the incoming ion reconstructed in the beam tracker and the coordinates of the reconstructed vertex, subtracting the contribution of the beam tracker resolution. The interaction point was identified using reconstructed vertices: the primary vertex was defined as the one having the highest number of tracks attached (more than one vertex per collision is in general present). The analyzed data were divided in three centrality bins, as summarized in table 1. The zero-degree calorimeter was designed to operate at much higher incident beam energies ($158 \text{ AGeV}$) [9]: its resolution at such low energy did not allow to set more centrality bins. The systematical error is evaluated to be of the order of 1%.

Vertices were found by reconstructing tracks in the vertex telescope and the algorithm provides the three coordinates of each vertex. Quality cuts were applied on the tracks to reject those not originating from the reconstructed vertices and fake ones, i.e. tracks composed of
Table 1. Centrality bins for the Pb-Pb run.

| % of $\sigma$ | b (fm) | $N_{\text{Part}}$ |
|---------------|--------|-------------------|
| 0-10%         | 4.0    | 305               |
| 10-20%        | 5.9    | 228               |
| 20-35%        | 8.1    | 147               |

Table 2. Pb-Pb results. Results from the cluster analysis. Only statistical errors are shown.

| % of $\sigma$ | $\eta_{\text{max}}$ | $(dN/d\eta)_{\text{max}}$ | $(dN/d\eta)/(0.5 \times N_{\text{Part}})_{\text{lab}}$ |
|---------------|----------------------|-----------------------------|----------------------------------------------------------|
| 0-10%         | 2.2 ± 0.1            | 166 ± 5                     | 1.09 ± 0.03                                              |
| 10-20%        | 2.2 ± 0.1            | 128 ± 7                     | 1.12 ± 0.05                                              |
| 20-35%        | 1.9 ± 0.2            | 90 ± 4                      | 1.22 ± 0.04                                              |

Table 3. Pb-Pb data. Results from the track analysis. Only statistical errors are shown.

| % of $\sigma$ | $(dN/d\eta)_{\text{max}}$ | $(dN/d\eta)/(0.5 \times N_{\text{Part}})_{\text{lab}}$ |
|---------------|-----------------------------|----------------------------------------------------------|
| 0-10%         | 171 ± 2                     | 1.12 ± 0.02                                              |
| 10-20%        | 127 ± 2                     | 1.11 ± 0.02                                              |
| 20-35%        | 73 ± 1                      | 0.98 ± 0.02                                              |

clusters produced by different physical particles. A cut was applied in order to select good vertices, constraining their transverse coordinates using the ion tracks reconstructed in the beam tracker. Off-target events (e.g. events produced in the beam tracker sensors or window) were rejected.

The analysis of this sample was done with two different approaches: counting clusters on the individual planes and using reconstructed tracks. The former approach permits to cover a broader pseudorapidity window, the latter is less sensitive to systematical effects, like $\delta$-rays contamination. On the other hand the contribution due to fake tracks is not negligible with such few planes.

In the cluster analysis, data from each target-plane combination were analyzed independently and corrected for acceptance and detector efficiency using a Monte Carlo simulation. The events in which a fragment of the ion had a second interaction (re-interaction events) were rejected. The contribution of secondary particles and $\delta$-rays was evaluated (using UrQMD 1.2 and GEANT 3.21) and subtracted. After corrections the distributions from the three targets were in good agreement with each other. The final distributions (figure 4(a), systematical errors only are shown), covering the rapidity window $2 < \eta < 4.5$, were fitted with Gaussians, giving the values reported in table 2.

The track analysis covered a smaller pseudo-rapidity window ($2.5 < \eta < 4$). The analysis was performed independently for the three targets and only tracks originating from the primary vertex were taken into account. Raw data were corrected for acceptance, fake tracks and pixel efficiencies. The region at the borders of the acceptance was excluded from the analysis. The final distributions were fitted with a Gaussian, fixing the value of mid-pseudorapidity to $\eta = 2.1$ from the cluster analysis, as the mid-rapidity region was not accessible with this method. The results are summarized in table 3 and shown in figure 4(b) (only statistical errors are plotted).

In both analyses detailed pixel-by-pixel efficiency maps were used to correct the data. These analyses are still at a preliminary stage: the differences observed between the cluster and the track analysis for the most peripheral bin are under study and likely to be due to the contamination by $\delta$-rays (cluster analysis) or fake tracks (track analysis). The systematical error is estimated to be around 12%.
4.2. In-In collisions at 158 AGeV

The layout of the telescope used in the October - November 2003 indium run is depicted in figure 5(a). During this run, 16 planes (8 small and 8 large) were used providing 12 tracking points. All the detectors described in section 2 were included in the setup. Seven 1.5 mm thick indium targets were installed in a vacuum box. Figure 5(b) shows the Z-vertex distribution obtained with the vertex telescope. The peaks corresponding to the targets and to the target-box windows are clearly seen in this plot.

Data were collected using a “mixture” of different triggers, including the dimuon trigger and the minimum-bias triggers from the beam tracker and the ZDC detectors. For the multiplicity analysis the sub-sample of events corresponding to the minimum-bias triggers was selected. Runs with different settings in the vertex dipole magnet were analyzed (no field, positive current, negative current). Similar cuts to those applied in the Pb data track analysis were used in order to reject vertices not produced in the targets or not correlated with the incoming ion. Furthermore, cuts to reject pile-up and reinteraction events were applied. Those cuts are needed because of the higher beam intensity during the indium run. In particular, pile-up events were rejected using the time stamp of clusters reconstructed in the beam tracker, profiting from the good time resolution of this detector (1.7 ns).

Reconstructed events surviving the cuts were corrected for acceptance, fake tracks and pixel efficiencies, evaluated with a Monte Carlo simulation. The region at the borders of acceptance was excluded from the analysis. The corrections were evaluated in the three centrality bins and for the 7 targets independently. As opposed to the Pb data analysis, at the present stage of the analysis detailed efficiency maps were not used, but an overall 95% efficiency was taken into account [10]. However, these are not expected to change the results, since with a 12 tracking point telescope an inefficiency in any particular pixel does not change the tracks kinematics.

The data were divided in three centrality bins, as summarized in table 4. Although the zero-degree calorimeter resolution allows us to define more centrality bins at this energy, only three bins were used at this early stage of the analysis. The systematical error on the definition of the
number of participants is of the order of 1%.

The results of this analysis are shown in table 5 and figure 7 for the data with positive and negative vertex field (only statistical errors are shown). The results for the two samples are found to be compatible within 10%. The final distributions were fitted with a Gaussian. The value of mid-pseudorapidity was fixed to $\eta = 3.14$ using the outcome of a Monte Carlo simulation, as the midrapidity region was not accessible. The systematical error is estimated to be around 15%. The main source of systematical uncertainty is the $p_T$ dependence of the acceptance with

| % of $\sigma$ | b (fm) | $N_{Part}$ |
|---------------|--------|-----------|
| 0-11%         | 2.6    | 179       |
| 11-24%        | 4.9    | 121       |
| 24-45%        | 7.1    | 61        |
Figure 7. Pseudorapidity distributions for three centrality bins in In-In collisions at 158 A·GeV. The curves were obtained by fitting the experimental points with a Gaussian.

Table 5. Results of the InIn data analysis. Only statistical errors are shown.

| Centrality | (dN/dη)_{max} | (dN/dη)/(0.5 \times N_{Part})_{lab} |
|------------|----------------|-----------------------------------|
| 0-11%      | 181.5 ± 0.8    | 2.02 ± 0.01                       |
| 11-24%     | 117.1 ± 0.5    | 1.93 ± 0.01                       |
| 24-45%     | 58.7 ± 0.3     | 1.93 ± 0.01                       |

the vertex magnetic field. Hence the acceptance correction depends on the event generator used (either VENUS or UrQMD, in this work). The analysis will be refined by using bi-dimensional acceptance corrections in the [η, p_T] plane.

5. Conclusions and outlook
The NA60 detector has been presented in this paper. Although it is mainly a dimuon experiment, its apparatus is also capable of measuring charged particle multiplicities. The main detector used for this purpose, the silicon vertex telescope, has been described.

Preliminary results on charged particle multiplicities, measured as a function of centrality and pseudorapidity, from two colliding systems at different energies have been discussed.

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