Heavy Ion Results from the ALICE Experiment

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1 Introduction

The ALICE experiment has been specifically designed to study strongly interacting matter under the most extreme conditions realized to date in terms of initial temperature and pressure [1, 2]. To this end the experimental apparatus has been optimized for particle identification and momentum resolution in the very high multiplicity environment encountered in Pb-Pb collisions at the LHC. The central barrel of the experiment is capable of measuring charged and (via decays) neutral hadrons, as well as electrons and photons in the pseudo-rapidity range of $|\eta| < 0.9$. Additional detectors are used to for triggering, centrality selection, and an extended coverage for charged particle multiplicity measurements. The central barrel is complemented on one side ($-4 < \eta < -2.5$) by a muon spectrometer behind a massive absorber. Details of the various detector systems can be found in Ref. [3]. With the exception of the Transition Radiation Detector (TRD) and the Electromagnetic Calorimeter (ECAL) the entire detector has been completed and commissioned and has been successfully collecting data.

2 Detector Performance

In the first long heavy ion run at the LHC a luminosity of about $\mathcal{L} \approx 2 \cdot 10^{25}$ cm^{-2}s^{-1} was achieved with 114 bunches of $7 \cdot 10^7$ Pb ions per bunch leading to a minimum bias interaction rate of about 100 Hz. The centrality trigger was derived from two detectors systems, the Silicon Pixel Detector (SPD, $|\eta| < 1.5$) and two scintillator hodoscopes (VZERO-A, 2.8< η <5.1; VZERO-C, -3.7< η <-1.7). In total about 30 million minimum bias triggers were recorded.

A few examples of the performance of some of the detectors of the inner barrel are shown in Figure 1. The top left panel shows the specific energy loss measured in the Time Projection Chamber (TPC) versus the rigidity as determined from the tracking

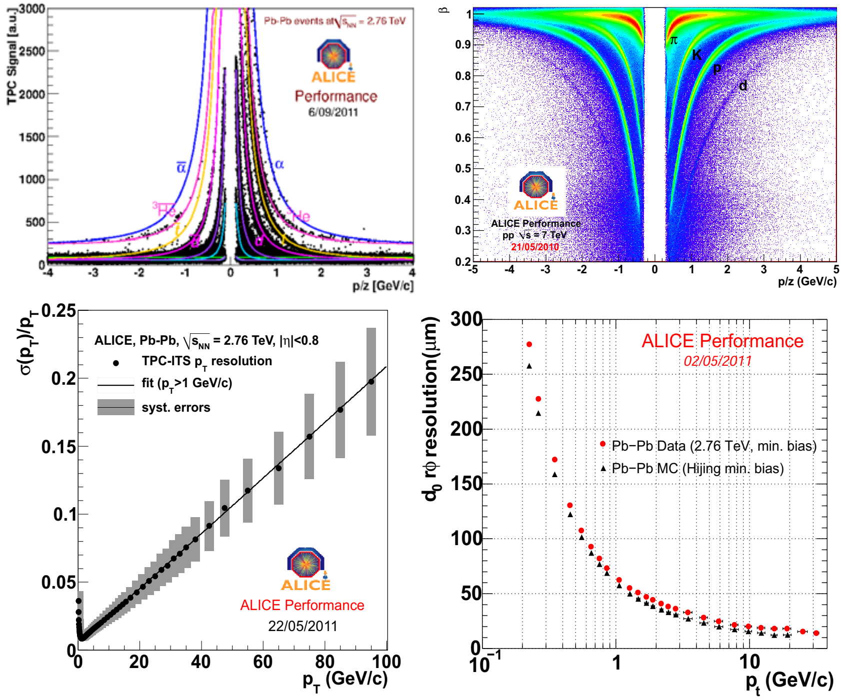

Figure 1: Specific energy loss vs. rigidity as measured in the TPC (top left), velocity from TOF vs. rigidity (top right), momentum resolution from tracking in the ITS and TPC (bottom left), and secondary vertex resolution of the ITS in Pb-Pb collisions (bottom right).

for positive and negative particles. It demonstrates the power of this device to even identify anti-Helium particles. The top right panel displays the measured velocity β from the Time-of-Flight system (TOF) again versus rigidity, clearly showing the separation power for π, K, p of this device out to several GeV/c. The performance of the combined tracking is shown in the lower left panel, where a combined resolution of the Inner Tracking System (ITS) and the TPC reaches $\sigma(\mathrm{p_T})/\mathrm{p_T}$ =20 % at 100 GeV/c. While the bottom right panel shows that the secondary vertex resolution in heavy ion collisions is already very close to the design resolution, a key ingredient for the identification of charmed mesons.

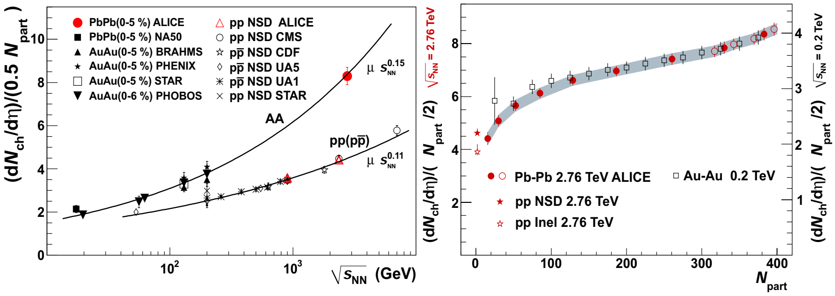

Figure 2: Multiplicity dependence on center of mass energy for pp and AA collisions (left panel), multiplicity dependence on collision centrality for different energies (right panel). (Measured multiplicities are scaled by the number of binary collisions.)

3 Results

The very first result from Pb-Pb collisions at the LHC concerned the charged particle multiplicity density in the 5% most central collisions. The measured value at $\sqrt{s_{\rm NN}}$ =2.76 TeV is $dN_{ch}/d\eta$ =1584 ± 4(stat) ± 76(syst)[4]. In the plot depicted in the left panel of Fig. 2 it has been normalized to the corresponding number of binary collisions as determined via a Glauber Monte Carlo. The multiplicity is up by a factor of 2.2 compared to heavy ion collisions at RHIC. The multiplicity per participant pair is up by a factor of 1.9 compared to pp(p$\bar{\rm p}$) collisions at comparable energies. As a function of centrality this multiplicity increases by about a factor of 2 between the most peripheral and central collisions (right panel of Fig. 2), strikingly

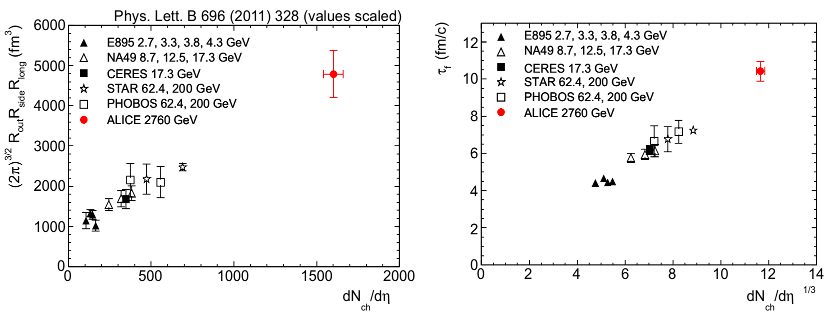

Figure 3: Evolution of the source volume from HBT radii (left panel) and decoupling time (right panel) as a function of the (cubic root) of the rapidity density.

similar in behavior as compared to RHIC energies[5].

Hanbury-Brown/Twiss-interferometry of identical charged pions has been used to characterize the volume and the lifetime of the emitting source[6]. Using Gaussian parameterizations, the properly normalized product of the radii is shown in the left panel of Fig. 3, indicating that the homogeneity volume is more than three times the size of a Pb nucleus (roughly a factor of two larger as compared to RHIC) and the characteristic decoupling time about 30 % longer (right panel of Fig. 3).

The large expansion is accompanied by strong elliptic flow (v_2) indicative of a strongly interacting medium with very small viscosity. The p_T integrated v_2 as measured in Pb-Pb collisions has been compared to results obtained at lower $\sqrt{s_{NN}}$ [7]. An increase in the absolute value of about 30 % with respect to the top RHIC energy is observed. It can be attributed to a corresponding increase in $\langle p_T \rangle$. This supports the notion that the medium created in Pb-Pb collisions at the LHC is very similar, i.e. again close to an ideal liquid, as at RHIC energies. Given the larger volume and lifetime this should - in conjunction with the measurement of higher harmonics - provide strong constraints on the value of the shear viscosity over entropy density ratio (η/s). The top panel in Fig. 4 shows the p_T-differential flow employing two- and four-particle cumulants ($v_2\{2\}$,$v_2\{4\}$) for one selected centrality class (40-50 %). In the bottom of that figure measurements of $v_2\{4\}$ at different centralities are compared to measurements of Au-Au collisions at $\sqrt{s_{NN}}$ = 0.2 TeV. Again, the numerical values are in striking agreement, although the center-of mass energies differ by more than order of magnitude.

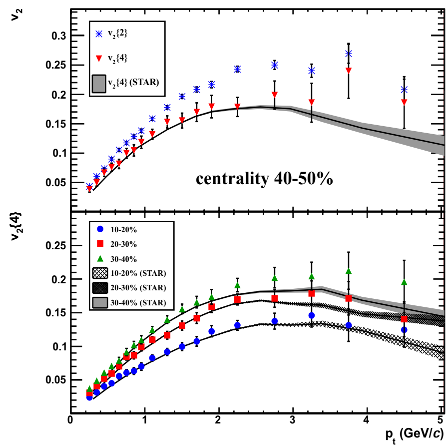

Figure 4: Top: $v_2(p_T)$ from two- and four-particle cumulants in Pb-Pb collisions (40-50% centrality). Bottom: $v_2\{4\}(p_T)$ for different centrality classes (symbols) compared to STAR measurements (bands).

With the measurement of transverse momentum spectra of different particles in pp collisions at $\sqrt{s}$ =2.76 TeV, it is now possible to directly compare to the spectra measured in Pb-Pb collisions to determine the so-called nuclear modification factor R_{AA}. The left panel of Fig. 5 shows this nuclear modification factor for three differ-

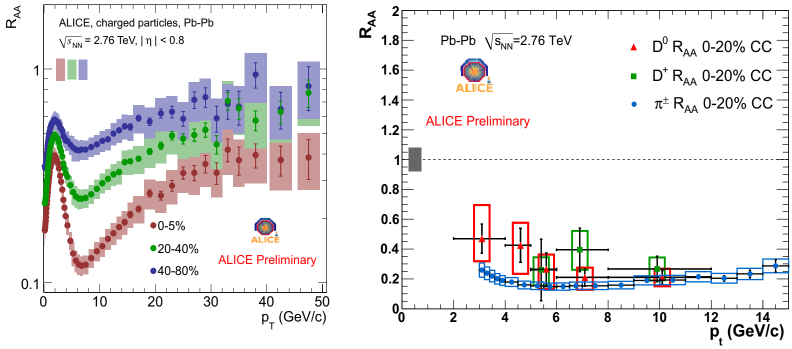

Figure 5: The nuclear modification factor R_{AA} of charged hadrons as a function of $p_{\rm T}$ for three different centrality classes (left panel); comparison of the nuclear modification factor for D-mesons and charged pions for the 20 % most central collisions (right panel).

ent centralities. A pronounced minimum is clearly visible around $\rm p_T \approx 6-7$ GeV/c. This minimum is significantly lower than the one measured at RHIC. With increasing transverse momentum R_{AA} increases and flattens out. Also, in going from central to peripheral collisions the differences in R_{AA} diminish. It is through the excellent secondary vertex reconstruction that it is possible to also measure the nuclear modification factor for charmed mesons. In the right panel of Fig. 5 this shown for reconstructed $\rm D^+$ ($\rm D^+ \to K^+\pi^+\pi^-$) and $\rm D^0$ ($\rm D^0 \to K^+\pi^-$) in comparison to identified pions. The observed suppression for charmed mesons in nuclear collisions as compared to pp collisions is - within uncertainties - of the same size.

4 Summary

After many years of preparation the ALICE experiment came into operation in 2009. The detector performs in many respects very close to design specifications. With the first heavy ion run and the respective pp reference runs it is now possible to fully explore hot and dense nuclear matter at unprecedented temperatures and densities. In general, a smooth evolution of those observables already studied at RHIC and even at the SPS is observed. A clear indication for a rise in the nuclear modification factor R_{AA} at high $\rm p_T$ has been established. Given the much increased reach in transverse momentum, the access to genuine hard probes, and the superb particle identification capabilities, ALICE is now well positioned to quantitatively explore the properties of the matter created in nuclear collisions at the LHC.

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