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High $p_{\rm T}$ identified particle production in ALICE.

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Abstract

The ALICE experiment is a dedicated heavy-ion physics detector at the LHC with unique capabilities for studying identified particle production. In this proceeding preliminary results for $R_{\rm AA}$ of π and K+p (sum), are reported, based on measurements in pp at $\sqrt{s}$ = 2.76 TeV and Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV. The results are compared to theoretical predictions and measurements at RHIC.

Keywords:
LHC, ALICE experiment, spectra, identified particle production, high pt, $R_{\rm AA}$

1. Introduction

The production of particles at high $p_{\rm T}$ in pp collisions can be described using perturbative QCD. In Pb-Pb collisions these hard probes are important tools for studying the medium formed, as the initial state production can be established from pQCD and binary scaling of pp results.

The observed yield of high-$p_{\rm T}$ particles is much smaller than expected from binary scaling because of strong final state interactions with the surrounding dense medium [1]. Experiments at RHIC have shown that this modification is very different for mesons and baryons [2, 3, 4].

The results from RHIC have lead to theoretical speculations on particle specie dependent effects (PID effects for short) at high $p_{\rm T}$ that are extremely attractive to test at LHC where the production cross section for hard processes is much larger than at RHIC energies. In the following we shall discuss 3 regimes of $p_{\rm T}$ (low, intermediate, high) and their PID effects in Pb-Pb collisions.

The main PID effect at low $p_{\rm T}$, $p_{\rm T} < 2$ GeV/c, is flow. For hydrodynamic flow the PID dependence is purely due to mass differences (but the final spectra are affected by resonance decays). At RHIC there has been speculation that the baryon to meson anomaly (and elliptic flow) observed at intermediate $p_{\rm T}$, $2 < p_{\rm T} < 8$ GeV/c, is related to the recombination of flowing valence quark like degrees of freedom rather than hydrodynamic flow. There have been predictions that these effects should extend out to much higher $p_{\rm T}$ at LHC [5]. At high $p_{\rm T}$, $p_{\rm T} > 8$ GeV/c, the observed PID effects should be mainly due to the interaction of the hard probe with the medium. Following [6] we can imagine that the hard parton directly exchanges quantum numbers, e.g. baryon number, with the medium, but also that the color flow of the fragmentation is modified by radiative energy loss and interactions with medium partons, and that this gives large effects due to the changes in invariant mass. The latter effect seems very generic, and in [6] this interplay is modeled via enhanced parton splitting functions and they find large effects on the particle ratios (relative to "pp fragmentation") inside the jets even out to very large $p_{\rm T}$. It is in particular these high $p_{\rm T}$ PID effects we are interested in addressing here.

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2. High p_T PID in the ALICE experiment

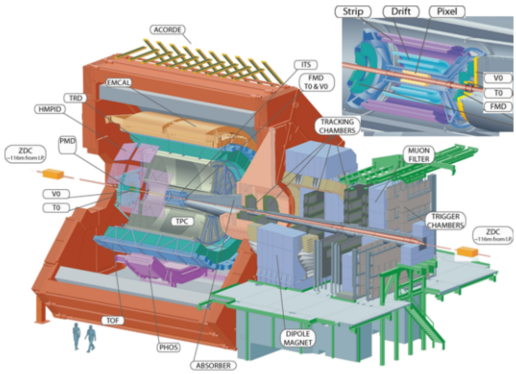

Figure 1: Schematic view of the ALICE experiment. The main detector used for the analysis reported here is the TPC located near the center of the the central barrel (inside the L3 magnet).

Figure 1 shows the layout of the ALICE experiment [7]. ALICE is a dedicated heavy-ion experiment with full azimuthal coverage around mid-rapidity (central barrel located inside the L3 magnet) and a dedicated forward muon tracking system. The results reported here rely mainly on the excellent tracking and PID capabilities of the Time Projection Chamber (TPC) [8]. The p_T resolution for primary tracks associated with hits in the Silicon based Inner Tracking System (ITS) is better than 5% at $p_T = 20$ GeV/c.

In the ALICE experiment it is possible to identify particles with very high transverse momentum, $p_T \gg 3$ GeV/c. Charged pions and kaons+protons (together) can be identified from the dE/dx, thanks to the separation on the relativistic rise, and K^0_s and Λ can be identified from their V^0 weak decay topology [9]. The identification of π^0 with the calorimeters and via conversion of photons was covered in another presentation [10].

3. High p_T results

ALICE has recently submitted results on flow of identified particles, v_2 and v_3, at high p_T for publication [11]. The main results we shall quote from there is that for $p_T > 8$ GeV/c, v_3 is small and there does not seem to be large PID effects for v_2. This suggests that at high p_T genuine flow effects are small, i.e., we are in a dominantly hard/jet regime.

In the rest of this section we discuss PID on the relativistic rise of the TPC dE/dx. The dE/dx is obtained as the truncated mean of the $0-60\%$ lowest charge samples. The performance and stability of the dE/dx, with respect to e.g. pressure variations, is improved in the following two ways. Reconstructed space points where the charge is deposited on a single pad, that are not used for track fitting, are included in the dE/dx calculation. Missing hits in between rows where hits are found are assigned a virtual charge of the lowest reconstructed charge cluster on the track to account for threshold effects.

Figure 2 shows the dE/dx vs p for Pb-Pb data. We note that for $p > 3$ GeV/c pions, kaons, and protons can in principle be separated. The first step in the analysis is the extraction of parameterizations for $\langle dE/dx \rangle (\beta\gamma)$ and $\sigma(\langle dE/dx \rangle)$. The extraction is done independently for each pp sample and Pb-Pb centrality class using a 2-dimensional fit to similar data as shown in the figure. For this analysis a constant relative resolution, $\sigma / \langle dE/dx \rangle = const$, has been used.

For PID the quantity $\Delta_\pi = dE/dx - \langle dE/dx \rangle_\pi$ has been studied as a function of p_T. Figure 3 shows an example of Δ_π spectra for different data sets in 2 p_T intervals. The estimated distributions are fitted using a sum of 4 Gaussians (π, K, p, and e) where the mean and width of each Gaussian has been constrained from the parameterizations of $\langle dE/dx \rangle$

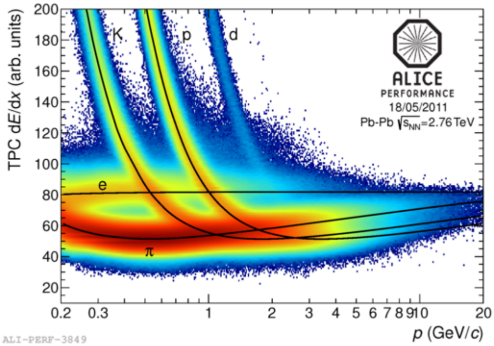

Figure 2: TPC dE/dx vs p. The curves show the ⟨dE/dx⟩ for π, K, p, and e.

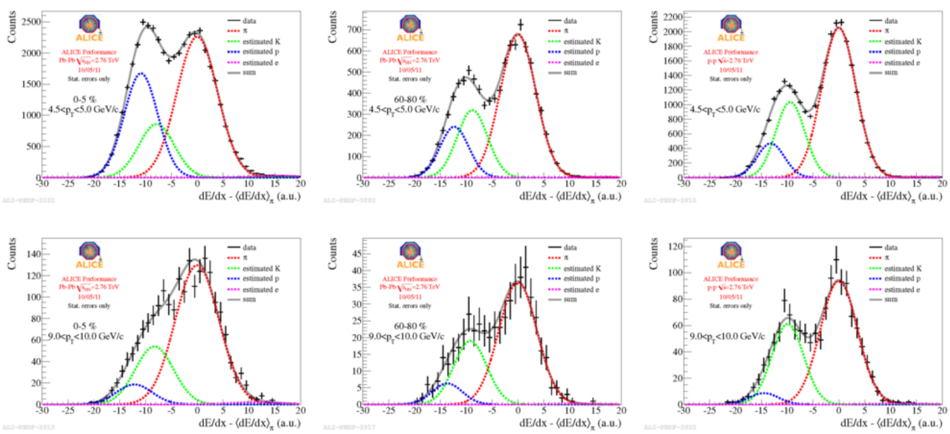

Figure 3: Δ_π distributions fitted with a sum of 4 Gaussians for two p_T intervals, $4.5 < p_T < 5.0$ GeV/c (upper) and $9.0 < p_T < 10.0$ GeV/c (lower), in central (left) and peripheral (center) Pb-Pb, and pp (right) collisions.

and σ. It is clear already from the Δ_π spectra that the composition of particle species is very different in central Pb-Pb from peripheral Pb-Pb and pp. Furthermore this difference seems to be greatly reduced or gone at higher $p_{\rm T}$. This is similar to the baryon-meson enhancement observed for $\Lambda/{\rm K}^0_s$ [9], but we do not here try to separate the kaons and protons in the Δ_π distributions (this analysis was shown at Quark Matter 2012 and needed a refined description of $\langle {\rm d}E/{\rm d}x\rangle$ and σ).

From the fit to the data we extract the fraction of pions. To extract pion spectra we use the $\frac{{\rm d}^2N_{\rm ch}}{{\rm d}p_{\rm T}{\rm d}\eta}$ of unidentified charged particles [12] to normalize the results using the equation:

$$\frac{{\rm d}^2N_\pi}{{\rm d}p_{\rm T}{\rm d}\eta} = \frac{{\rm d}^2N_{\rm ch}}{{\rm d}p_{\rm T}{\rm d}\eta} \times \frac{\epsilon_{\rm ch}}{\epsilon_\pi} \times \frac{Y_\pi}{Y_{\rm ch}}, \quad (1)$$

where $Y_\pi/Y_{\rm ch}$ is the uncorrected pion fraction obtained from fits like in Figure 3 and $\epsilon_\pi/\epsilon_{\rm ch}$ is the relative pion efficiency which is independent, within a 2% systematic uncertainty, of centrality and $p_{\rm T}$ in the measured interval. To obtain rapidity spectra, a small correction is applied to convert the pseudorapidity interval ($|\eta| < 0.8$) into a rapidity interval.

The dominating systematic uncertainty on the extracted pion fraction has been estimated by releasing the constraints used in the Δ_π fits. It is around 3% for pp and 5% for Pb-Pb. For the spectra and $R_{\rm AA}$, the full systematic uncertainty of the unidentified analysis is also taken into account [12].

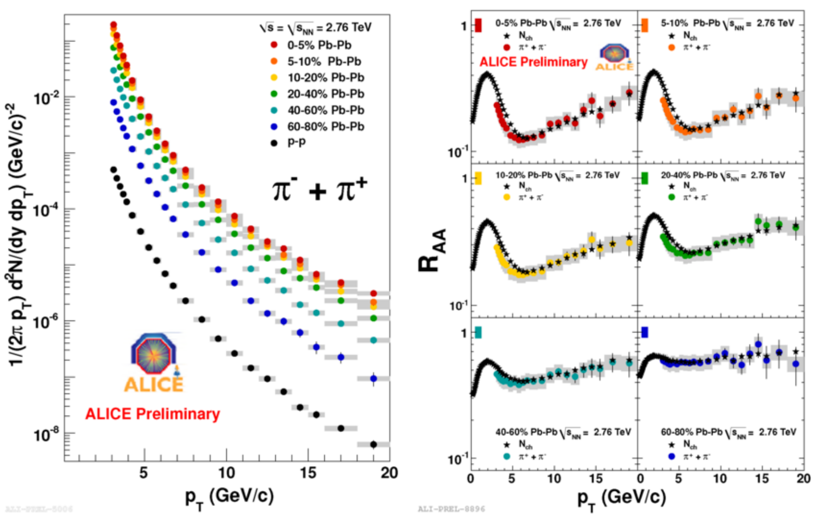

Figure 4: Left: the invariant yield for charged pions, $\pi^- + \pi^+$, as a function of $p_{\rm T}$ for different Pb-Pb centrality classes and pp. Statistical errors are shown by the vertical error bars. Systematic uncertainties are shown as gray boxes. Right: the $R_{\rm AA}$ computed from these spectra and compared to the $R_{\rm AA}$ for unidentified charged particles (black points) as a function of $p_{\rm T}$ for different centrality classes. Statistical (vertical error bars) and systematic (gray and colored boxes) are shown for the charged $\pi^- + \pi^+$ $R_{\rm AA}$. The colored boxes contain the common systematic uncertainty related to the nuclear overlap function and the pp normalization to the total inelastic cross section. Only statistical errors are shown for the unidentified charged $R_{\rm AA}$.

Figure 4 (left) shows the spectra for charged pions, $\pi^- + \pi^+$, for $3 < p_{\rm T} < 20$ GeV/c. From these spectra the $R_{\rm AA}$ can be computed:

$$R_{\rm AA} = \frac{\left(\frac{d^2N}{dp_{\rm T}dy}\right)_{\rm Pb\text{-}Pb}}{\langle T_{\rm AA}\rangle \left(\frac{d^2\sigma_{\rm INEL}}{dp_{\rm T}dy}\right)_{\rm pp}}, \quad (2)$$

where $\langle T_{\rm AA}\rangle$ is the nuclear overlap function obtained from a Glauber calculation for a given centrality class.

Figure 4 (right) shows the R_{AA} for charged pions compared to unidentified hadrons. For $p_T < 8$ GeV/c charged pions are more suppressed than unidentified particles from the bulk, while for $p_T > 8$ GeV/c the suppression is similar.

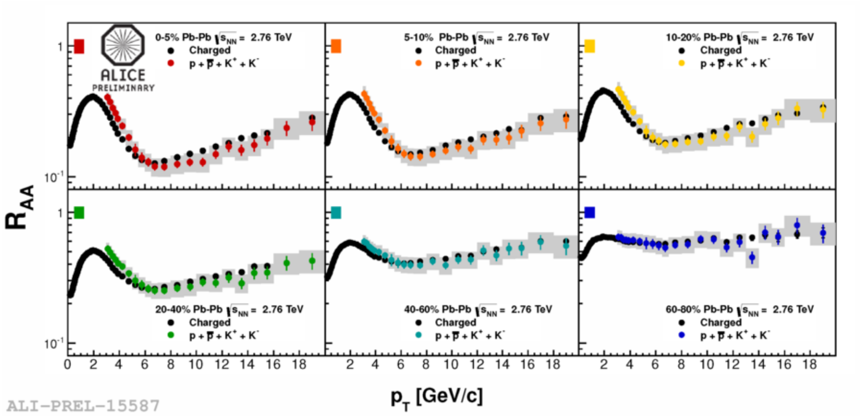

Figure 5: The figure shows the R_{AA} for the sum of kaons and protons compared to the R_{AA} for unidentified charged particles as a function of p_T for different centrality classes. Statistical (vertical error bars) and systematic (gray and colored boxes) are shown for the charged K+p R_{AA}. The colored boxes contain the common systematic uncertainty related to the nuclear overlap function and the pp normalization to the total inelastic cross section. Only statistical errors are shown for the unidentified charged R_{AA}.

Even we do not yet trust separately the fits of protons and kaons, the sum is stable. To enhance the significance of the previous results we can therefore make a similar analysis for the sum of K+p ($K^- + K^+ + \bar{p} + p$). The absolute magnitude of the systematic uncertainty is similar to that of pions, and the variation of the yield due to slightly different efficiency for K and p and rapidity correction even when changing the lower yield by ±50% is much smaller.

Figure 5 shows the results for R_{AA}. For $p_T < 8$ GeV/c charged K+p is less suppressed than bulk unidentified particles, as expected since pions are more suppressed in this region. For $p_T > 8$ GeV/c the suppression is similar.

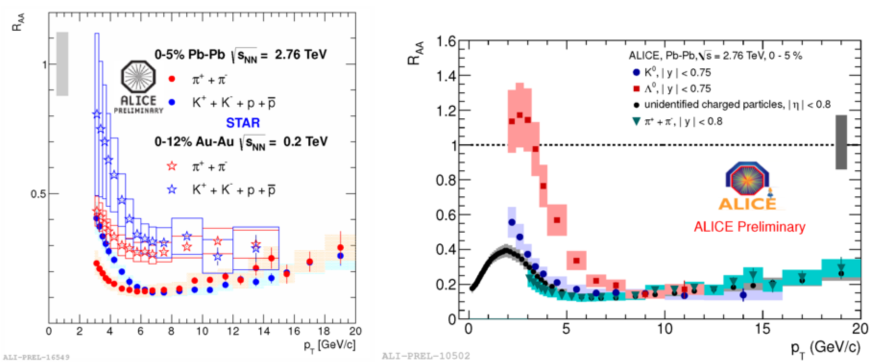

Figure 6: Left: R_{AA} for the sum of kaons and protons compared to the R_{AA} for pions for Pb-Pb 0-5 %. Similar measurements by the STAR experiment [13] are also included. Right: R_{AA} summary for light quark hadrons for Pb-Pb 0-5 %.

Figure 6 (left) shows a comparison between the results for charged pions and the sum of kaons and protons for the 0-5 % most central collisions. Similar results from STAR at RHIC have also been included. The result indicates that at high p_T large differences in suppression is only possible when K and p are studied separately. This is contrary to [6] where the particle ratios for K/π and p/π were both found to be enhanced within jets for $5 < p_T < 25$ GeV/c (and so K+p/π in central collisions is much larger than in pp collisions) [1].

4. Discussion

Figure 6 (right) shows a summary of R_{AA} for inclusive charged particles and some light quark hadrons: $\pi^- + \pi^+$, K^0_s and Λ. The preliminary results from ALICE on R_{AA} for identified particles suggest that at high p_T light quark hadrons are equally suppressed. The question which I want to speculate on here is what this results could indicate in terms of quenching.

In general for R_{AA} of high-p_T particles we are sensitive mostly to leading particle effects and there is some bias towards the surface and unmodified jets. ALICE also presented results at Hard Probes 2012 that show that the p/π ratio in a region around high-p_T triggers, after the bulk contribution has been subtracted, is similar to the expectations for pp [14]. STAR also presented a similar study but with less clear conclusions [15]. The bulk ratios can of course be affected by radiative energy loss and one would benefit from more advanced methods of jet-bulk separation, but the results suggest that identified particle production of subleading particles in jets is also not strongly modified.

If one compares to the possible PID effects at high p_T mentioned in the introduction, the most generic process that seems to be ruled out is strong modified color (gluon) flow in the fragmentation process [6]. It seems natural to assume that once the parton starts propagating through the medium both radiative energy loss and gluon shower radiation occurs. Taken these results to the extreme one might then propose that the parton fragmentation differentiates between these two types of radiation. One would then have to establish the physics that would decouple these processes, e.g., the energy loss could be radiated as "free" gluons.

There is a large theoretical activity on quantum interference effects and the effect on the energy loss/fragmentation. These results do not directly support the picture above, but have some of the ingredients in terms of coherence and decoherence effects that are different in the medium and in the vacuum, see e.g. [16] and references therein.

It is clear that the results from ALICE reported here could play an important role in guiding these challenging theoretical efforts.

5. Conclusions

The R_{AA} for π, K+p, Λ, and K^0_s at high p_T ($8 < p_T < 20$ GeV/c) seems to indicate that particle species dependent effects are, if present, small. This provides important input to models of the energy loss and may restrict color flow effects.

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