Scientific Report
2011-2013

The activities taking place in the above mentioned period were focused on the analysis of experimental data obtained using the ALICE experimental device at LHC-CERN in pp collisions at √s=7 TeV and development of theoretical and phenomenological models for their interpretation.

1. <u>Transverse momentum distributions for nearly isotropic and high multiplicity events in pp collisions at √s=7 TeV in the ALICE experiment at LHC</u>

a. Multiplicity dependence of the efficiency correction

The precision of the experimental transverse momentum distributions reconstruction strongly depends on the precision of the reconstruction efficiency. The dependence of the reconstruction efficiency on the multiplicity and event shape is mandatory to be addressed. Therefore, the efficiency as a function of the multiplicity estimated from “global tracks” based on a “weighting” procedure and the one as a function of “combined multiplicity” were studied in detail and compared with the one corresponding to “minimum bias”. The ratios between the efficiencies determined in different multiplicity bins relative to the minimum bias one can be followed in Fig.1.

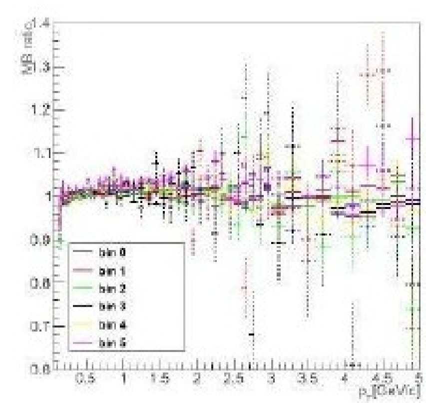


Fig. 1

b. Estimation of transverse momentum distributions contamination from weak decays and secondary interactions with the detector material

Another essential correction in determining the transverse momentum distributions is related to the contamination from weak decays and the interaction of the primary particles with the detector material. The dependence of this correction on multiplicity and event shape is very important. Estimations of the contribution of these processes for the charged and positive identified charged particles in different bins of multiplicity for the multiplicity estimated from “global tracks” or the combined multiplicity have been done. The conclusion was that these corrections do not depend on the multiplicity (with the exception of the largest multiplicity bin which was later investigated with much more statistics) as can be seen in Fig. 2 (left-”global tracks”, right-combined multiplicity).

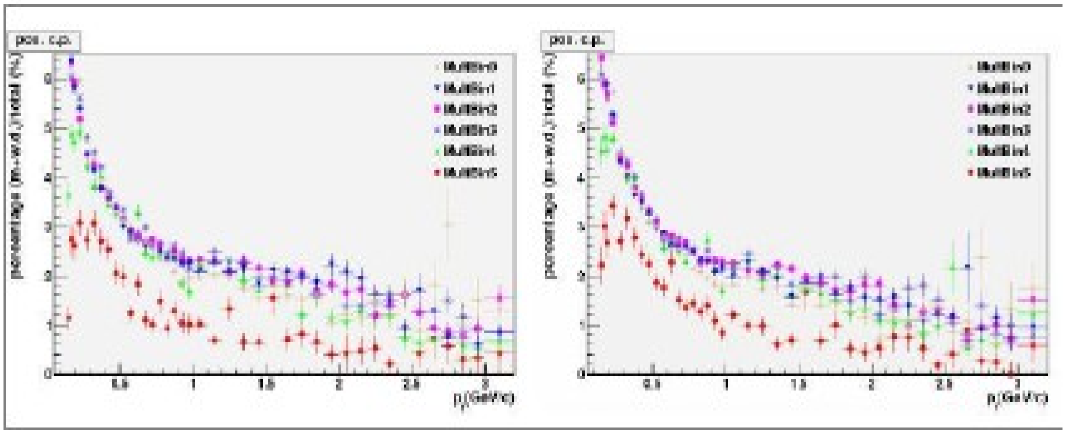


Fig. 2

These studies were reported at the meetings of the Light Flavor Physics Group of the ALICE Collaboration to which we belong and in two ALICE Internal Notes.

c. Transverse momentum distributions

Detailed studies on the multiplicity dependence of the corrections which have to be applied to the raw transverse momentum spectra for charged particles and identified positive hadrons for obtaining the primary spectra:

- the reconstruction efficiency of the charged particle trajectories
- the matching efficiency in position between the TPC and TOF detectors
- the identification efficiency of the positive hadrons
- impurities
- contaminations coming from the weak decays and charged particle interaction with the detector material
- trigger and vertex reconstruction efficiencies

and the systematic errors coming from:

- trajectory reconstruction
- the receipt for obtaining the input probabilities in the Bayesian identification method
- contaminations coming from the neighboring hadron species
- the identification efficiency
- the secondary particles

were done.

In Table I, first column, are presented the multiplicity domains in which the transverse momentum spectra analyses have been done.

Combined	Generated (PYTHIA) bin limits	Mean	Sigma
0 - 6	0 - 6	3.4	1.7
7 - 12	7 - 12	9.1	2.2
13 - 19	13 - 20	15.9	2.6
20 - 28	21 - 29	23.7	3.2
29 - 39	30 - 41	33.2	3.7
40 - 49	42 - 51	44.1	3.7
50 - 59	52 - 62	-	-
60 - 71	63 - 74	-	-
72 - 82	75 - 86	-	-

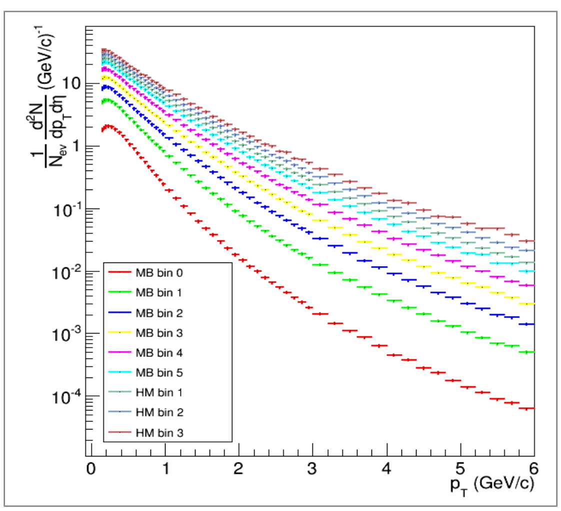
Table I

A synthetic presentation of the systematic errors can be followed in Table II.

		standard	low	high	pions	kaons	protons
MB	TPC clusters	70	60	80	0 - 4%	1 - 5%	0 - 3.5%
	TPC χ^2	4	3	5	0.5 - 4%	0 - 6%	0 - 6%
	DCAz	2 cm	1 cm	3 cm	<1%	0.5 - 2%	0.5 - 1.5%
	Mismatch probability	<0.01	<0.009	<0.011	<1%	0.5 - 3.5%	1%
	TRD presence	all tracks	WITH TRD	WITHOUT TRD	1 - 6%	2 - 6%	1 - 4%
	Tracking		dedicated study		4%	4%	4%
	Matching		dedicated study		3%	6%	4%
	PID priors	MB	mult <6	mult >49	<1%	0.5 - 2%	0.5 - 2%
	PID purity	none	-	>80%	0.5 - 4%	2 - 12%	1 - 4%
multiplicity bins	tracking efficiency	MB	7 - 12	29 - 39	<1%	2%	1%
	matching eficiency				negligible	negligible	negligible
	PID efficiency				<1%	0 - 30%	0 - 2%
	misidentified				<1%	<1%	<1%
	secondary particles	MB	-	mult >49	<0.5%	-	0.5%

Table II

Fig. 3 presents final transverse momentum spectra for charged particles in nine multiplicity ranges.



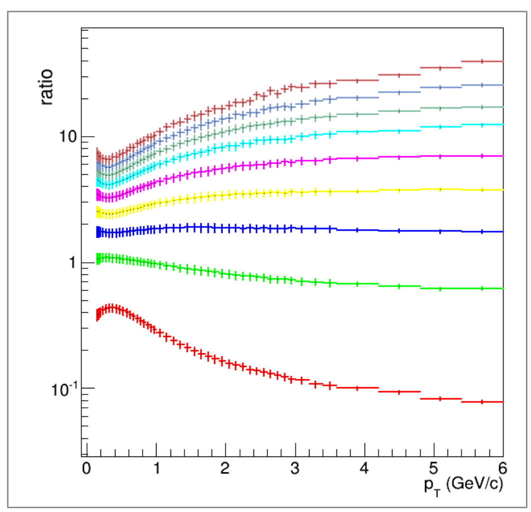


Fig. 3

Fig. 4

The ratios between the transverse momentum spectra for different multiplicities relative to the

non-conditioned spectrum in the charged particle multiplicity are presented in Fig. 4. A decrease of the ratio at small values of the transverse momentum can be observed, which enhances with increasing multiplicity, followed by an increase up to p_T values around 2.5 GeV/c after which the increase has a very small slope suggesting a saturation at values of the transverse momentum larger than 6 GeV/c. The decrease of the ratios at small values of the transverse momentum which enhances with increasing multiplicity, seems to indicate the existence of a collective type expansion.
In order to obtain the average value of the transverse momentum $\langle p_T \rangle$, the experimental spectra were fitted with different expressions suggested by phenomenological models as modified Hagedorn, Levy-Tsallis, UA1 and a combination between a Boltzmann type exponential distribution and a power-law in the transverse momentum suggested by Bylinkin et al. The best fits were obtained using the last expression. Thus, the extrapolation of the experimental spectra at smaller values than the measured ones of the transverse momentum was done based on the fits performed with this expression. The obtained results for $\langle p_T \rangle$ in the chosen multiplicity intervals are presented in Fig. 5.

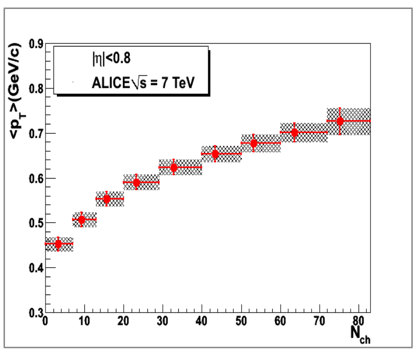


Fig. 5

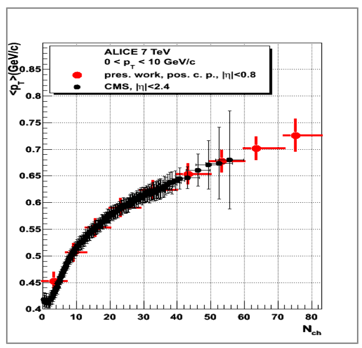


Fig. 6

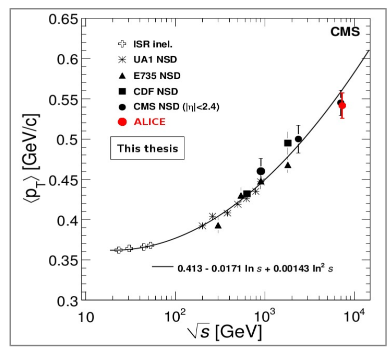


Fig. 7

In Fig. 6, a comparison between the results obtained by us and those obtained in the CMS Collaboration is done. As can be seen, the agreement is excellent, our data going to higher multiplicities relative to the CMS data. In Fig. 7 the $\langle p_T \rangle$ value without any condition in the charged particle multiplicity is presented by the red symbol. In the error bars limits, our result corresponds to the predicted value using the extrapolation of the results at lower energies and is in perfect agreement with the CMS Collaboration value.
Investigations related to the evolution of the presented results with the event shape will be done in the following studies.

In parallel, the analysis of the positive charged hadrons π^+, K^+ and protons (p) was done and their p_T spectra were obtained. The identification was done using the Bayesian method. The obtained spectra for the eight multiplicity ranges and without multiplicity condition (MB) are presented in Fig. 8, upper row. On the lower row the ratios of spectra for different multiplicity intervals relative to the MB one are presented. The tendency of the similar ratios corresponding to the charged particles, discussed above, is observed also for identified charged hadrons, the effect increasing with hadron mass from pions to protons. This trend, similar to the one observed in the Pb-Pb collision at the energy of 2.76 TeV, gives a stronger support to the hypothesis of existence of a collective type expansion. Another experimental result which supports this hypothesis can be followed in Fig. 9 where the relative ratios of the yields of the various positive hadron species as a function of p_T are presented on the upper row and their ratios relative to the

MB ratio in the lower row.

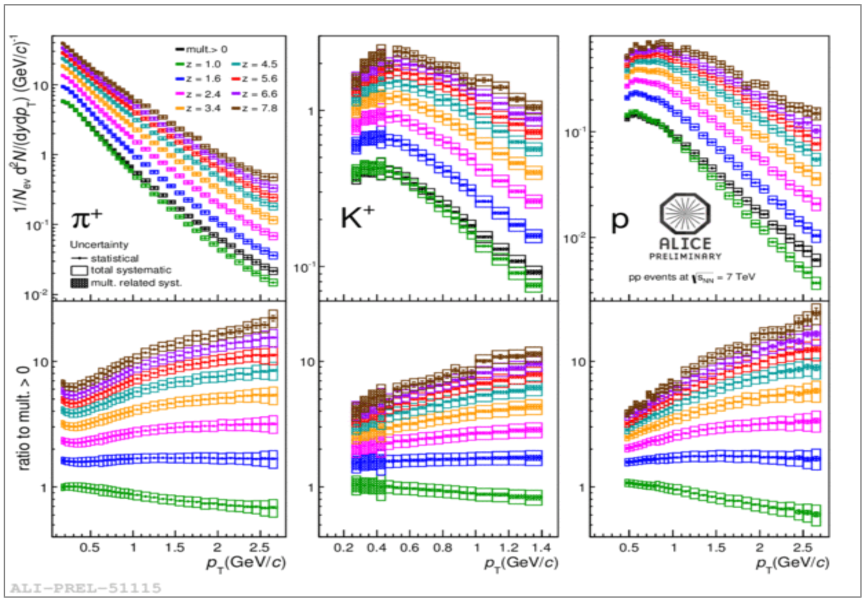


Fig. 8

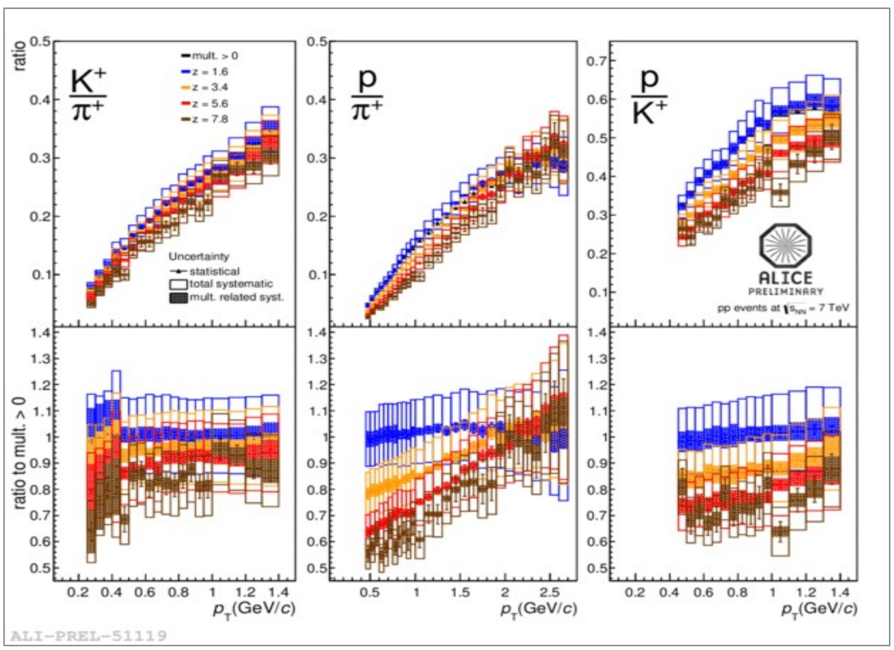


Fig. 9

Similarly to the procedure used for charged particles average transverse momentum values $\langle p_T \rangle$ for π^+, K^+ and p were obtained which are presented in Fig. 10. An increase of the average transverse momentum value as a function of multiplicity for all three species can be observed, the increase depending on the particle mass. By representing $\langle p_T \rangle$ as a function of particle mass for different multiplicity ranges, Fig. 11, an increase of the $\langle p_T \rangle$ slope as a function of mass with increasing charged particle multiplicity comes into prominence. This trend clearly shows the existence of a collective type motion on which a statistical type distribution is superimposed.

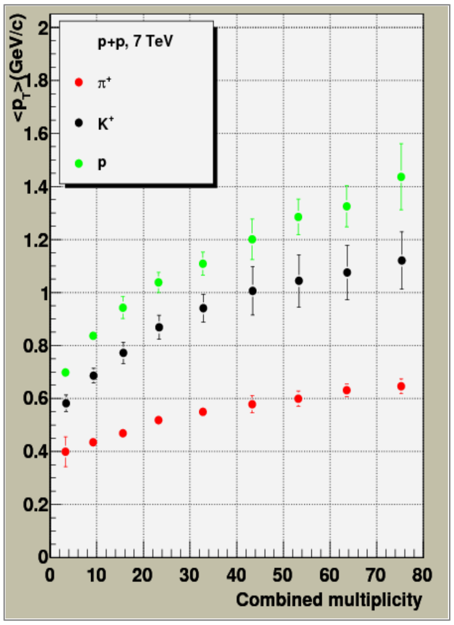


Fig. 10

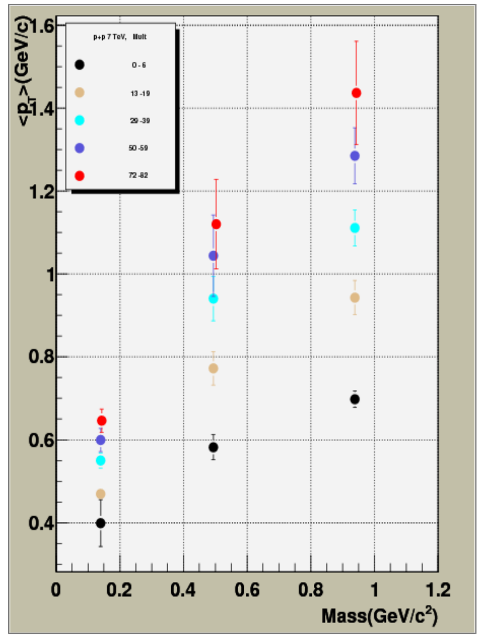


Fig. 11

As it was mentioned in the case of the charged particles, presently, simultaneous fits of the experimental spectra for a given multiplicity with Boltzmann-Gibbs Blast Wave expressions to obtain the kinetic freeze-out temperature, the expansion velocity and its profile, are in progress, followed by investigations related to the evolution of the presented results as a function of the event shape.

The obtained results were periodically reported in the Light Flavor Physics Analysis Groups of the ALICE Collaboration, Spectra PAG and Physics Forum, respectively and were subject of two detailed ALICE Internal Notes. It is worth to be mentioned that Fig. 8 and Fig. 9 were approved as official preliminary figures of the ALICE Collaboration and two papers are in progress.

2. Centrality dependence of the charged particle density at mid-rapidity in relativistic heavy ion collisions - energy scaling

One of the observables sensitive to the production mechanism of particles and the partonic structure of the colliding objects is the charged particle density and its dependence on the collision geometry. Detailed information on the centrality dependence of the charged particle density at mid-rapidity in A-A collisions is available starting from the AGS energies, to SPS and up to RHIC. At SPS and AGS energies, in the systematic errors limit, the normalized charged particle density $dN_{ch}/d\eta/(0.5N_{part})$ is quite constant as a function of centrality, namely N_{part} estimated on the basis of Glauber model. Although the dependence of the $dN_{ch}/d\eta/(0.5N_{part})$ shape on N_{part} is fairly similar at 130 and 200 GeV, a slight increase of the charged particle density can be observed from the peripheral to the central collisions. This behavior is enhanced at the LHC energy of 2.76 TeV where the published data by ALICE, ATLAS and CMS are in remarkable agreement. As it is expected and confirmed by the Monte Carlo Glauber model, in very peripheral collisions where the two diffusion zones of the two colliding nuclei are overlapping, preponderently binary collisions take place and the normalized charged particle density should have the same value as the charged particle density in inelastic nucleon-nucleon collisions. Based on the measurements at ISR, RHIC and LHC for pp collisions the scaling factors $(dN_{ch}/d\eta)^{pp\ 2.76\ TeV}/(dN_{ch}/d\eta)^{pp\ 0.2\ TeV}$ and

$(dN_{ch}/d\eta)^{pp\ 2.76\ TeV}/(dN_{ch}/d\eta)^{pp\ 0.0196\ TeV}$ can be obtained. Based on the Monte Carlo Glauber model the scaling factors in terms of the ratios of the average number of collisions suffered by the nucleons involved in interaction: $<N_{coll}^{2.76\ TeV}>/<N_{coll}^{0.2\ TeV}>$ and $<N_{coll}^{2.76\ TeV}>/<Nc_{oll}^{0.0196\ TeV}>$ were estimated as a function of N_{part}. By multiplying the normalized charged particle densities at 19.6 and 200 GeV, with the factors described above, values comparable with the results at 2.76 TeV are obtained (Fig. 12).
In conclusion, a scaling with energy of the centrality dependence of the charged particle density at mid-rapidity, based on the ratio between the charged particle density in inelastic pp collisions and the average number of collisions suffered by the struck nucleons at a given centrality at the corresponding energies, is shown to be valid in the limit of experimental errors.

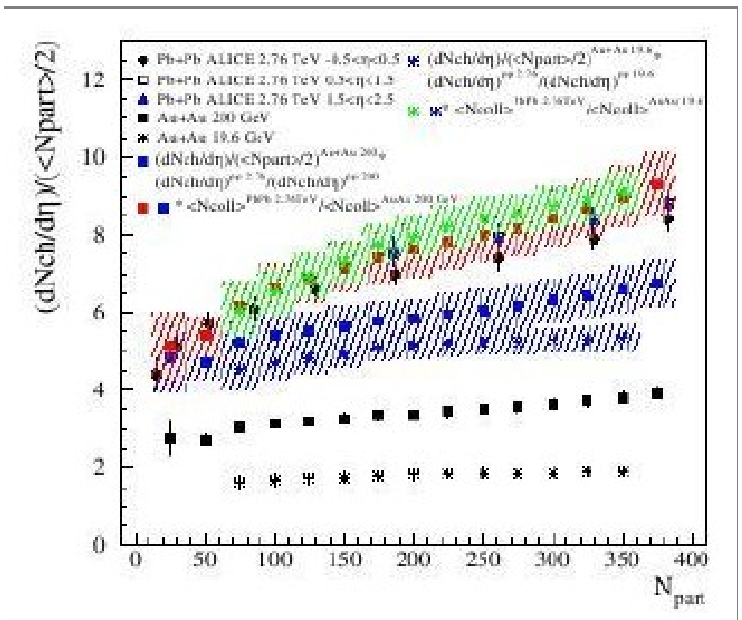


Fig. 12

In the same period, estimations based on the Glauber model for the average distances between the centroids of nucleons which participate to the Pb-Pb interaction at 2.76 TeV energy and p-Pb at 5.02 TeV energy were done and compared with the impact parameter in the pp collision at 7 TeV energy using the charged particle multiplicity distribution and various parameterizations of the hadronic matter distribution in the proton, essential in understanding the resemblances and differences in the behavior of various experimental observables in Pb-Pb, p-Pb and pp interactions at the LHC energies. The results are presented in Fig. 13.

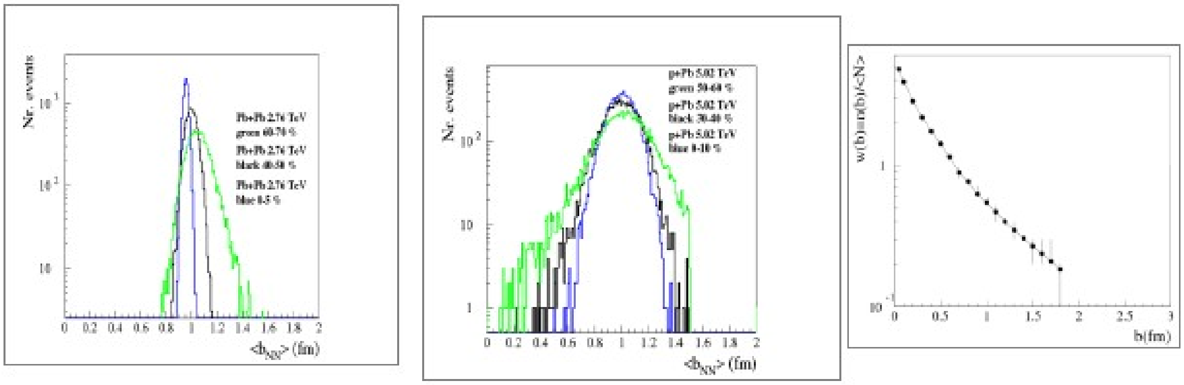


Fig. 13

3. <u>Predictions for p-Pb at $\sqrt{S_{NN}}$=5.02 TeV for testing the nuclear shadowing in the initial state at LHC</u>

The Monte Carlo type models HIJING1.0, HIJING2.0 and HIJING/BB2.0 were developed to study the production of hadrons in pp, p-A and A-A collisions. They are essentially two component models which describe the "hard" and "soft" processes. The jet production is calculated using the collinear factorized multiple minijet in pQCD. A p_0 cut has to be introduced in the average transverse momentum resulted after the final jet production, below whose value the interaction is considered non-perturbative and is characterized by the partonic "soft" cross section. The nucleon residues interact via "soft" gluons exchange described in string models. The pair of produced "hard" jets and the two excited residues are treated as independent strings which fragment in resonances which de-excite in the final hadrons. The string fragmentations in jets strongly depend on the string tension values. In HIJING 1.0 and HIJING2.0 a constant for the effective value of the string tension, k_0=1.0GeV/fm is used. At high initial incident energy the new nuclear physics is due to the possibility of superposition of the longitudinal multiple flux tube which leads to strong effects of the longitudinal color field. The effects of the strong color field are modeled in HIJING/BB2.0 by varying the value of the effective string tensions. In order to describe the pp collisions and central Pb-Pb data at LHC it was shown that an energy and mass dependence of the string tension average value has to be considered. All the HIJING type models implement nuclear effects as the nuclear modification of the partonic distribution functions, that is "shadowing" and "jet quenching" through an induced parton breakage process in medium. While in the first two models a constant cut p_0=2 GeV/c and a "soft" partonic cross section σ_{soft}=54 mb are used, in HIJINGBB2.0 for A-A collisions a dependence on energy and mass of the cut parameter $p_0(s,A)$ was introduced at the RHIC and LHC energies for not violating the geometric limit of the total number of minijets on transverse area unit. One of the main uncertainties in the charged particle multiplicity density calculation in Pb-Pb collisions is the nuclear modification of the partonic distribution functions, especially the low x gluon distributions. In the HIJING type models it is assumed that the parton distributions in a nucleus are factorized in a parton distribution in nucleon and the partonic shadowing factor. In the present calculations it is assumed that the shadowing effect for gluons and quarks is the same and the QCD evolution is neglected. Estimations of $dN_{ch}/d\eta$ and R_{pPb} as a function of pseudorapidity and of $(1/2\pi p_T)d^2N_{ch}/dp_Td\eta$ and R_{pPb} as a function of p_T for $|\eta|<0.8$ for minimum bias and 0-20% centrality (Fig. 14 and 15) in the p-Pb collision at 5.02 TeV were obtained.

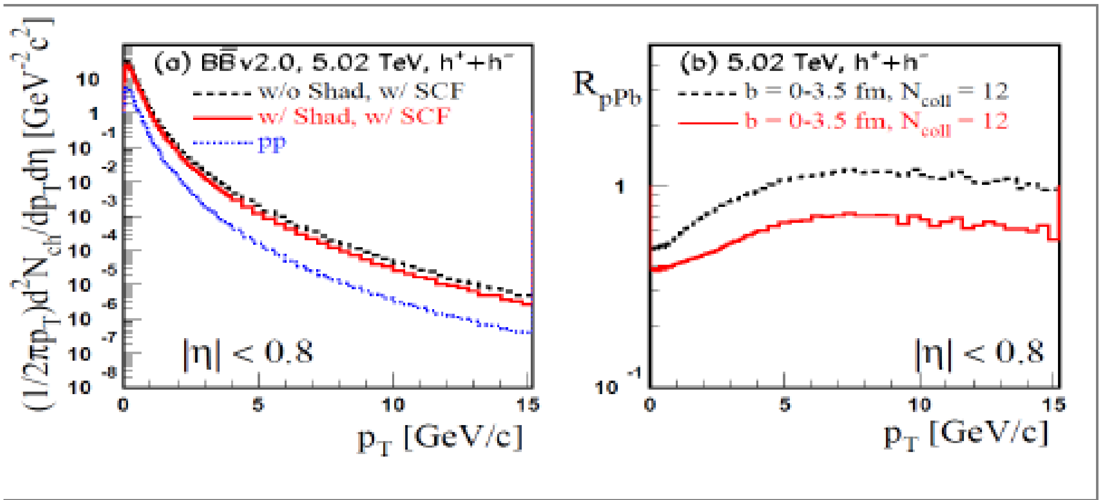


Fig. 14

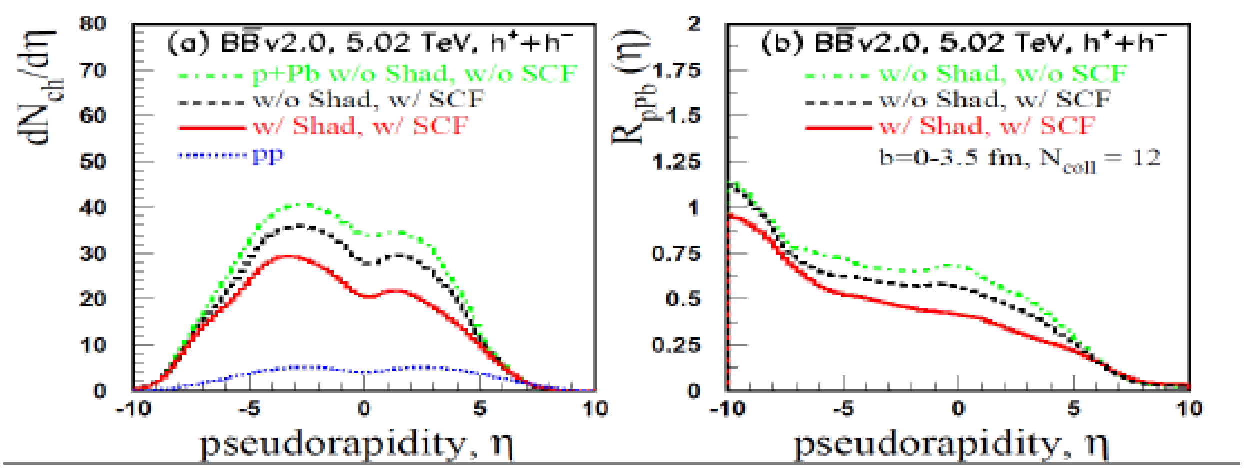


Fig. 15

Thus, even with a small sample of 10^6 events by studying $R_{pPb}(p_T)$ or the central relative to peripheral nuclear modification factor ($R_{CP}(p_T)$) a definite constraint on the nuclear shadowing implemented in different models inspired by pQCD and saturation CGC models, with a large impact on the interpretation of results obtained in nucleus-nucleus collisions (Pb-Pb) at the LHC energies, can be given.

The strong interaction shadowing phenomena and energy loss effects on the prompt production of charmed mesons D^0, D^+, D^{*+}, D_s^+ in central Pb-Pb collisions at 2.76 TeV were also investigated. The theoretical estimates in terms of transverse momentum spectra and nuclear modification factor $R_{AA}(p_T)=(1/N_{AA}^{evt})d^2N_{AA}/dp_Tdy/N_{coll}(1/N_{pp}^{evt})d^2N_{pp}/dp_Tdy$, were compared with experimental data obtained in the ALICE Collaboration.

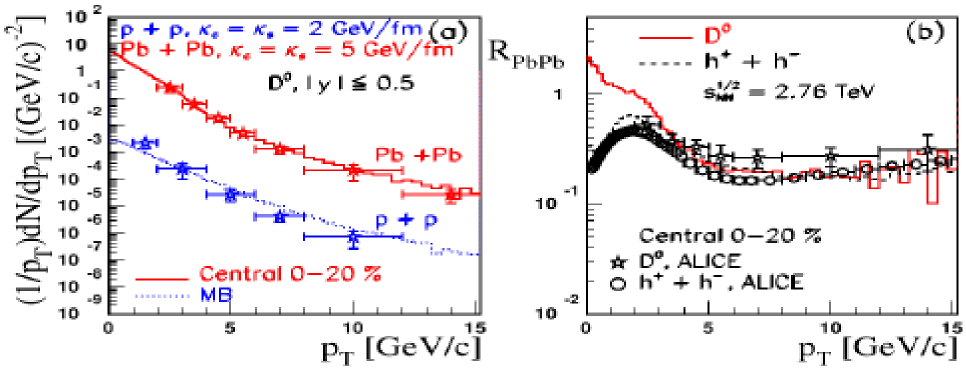


Fig. 16

As can be seen in Fig. 16, both the transverse momentum spectra and the nuclear modification factor as a function of p_T reproduce very well the experimental results, thus showing the importance of considering the above mentioned effects. The interaction strength, characterized by the so-called string tension and the energy loss at partonic level contribute to the supression observed in the nuclear modification factor in agreement with the experimental data. Calculations based on the same model were done for pp at 2.76 TeV and 7 TeV energies, these being reference data for the Pb-Pb case.

In the time period of the project presented in this report, our group had 29 presentations in different Working Groups of the ALICE Collaboration, four Internal Notes of the ALICE Collaboration were edited, we are co-authors to 94 papers published in ISI journals, 1 presentation and 2 posters at International Conferences , their list being included in the project data basis.

Project leader,

Prof. Dr. Mihai Petrovici