Scientific report
regarding the implementation of the project in the period
January-September 2016

I. Study of Non-Perturbative Particle Production in Strong Colour Fields. Collective Effects in p + Pb collisions.

The Large Hadron Collider (LHC) experiments are designed to measure hadronic, leptonic and photonic probes in a large acceptance and at extreme interaction rates and aim at a systematic investigation of Pb+Pb, p+Pb and p+p collisions in terms of collisions energy (from $\sqrt{s_{NN}}$ = 0.9 TeV up to $\sqrt{s_{NN}}$ = 13 TeV) and collision system size, with high precision and statistics.

Event generators like HIJING/BBbar v2.0 determine multiplicities from their models of soft particle production followed by fragmentation and hadronization. Theoretical predictions of particle production in high energy p+p, p+Pb and Pb +Pb collisions are based on the introduction of chromoelectric flux tube (strings) models [1], [2], [3]. String breaking mechanism approach is used for the conversion of the kinetic energy of a collision into field energy. Due to confinement, the color of these strings is restricted to a small area in transverse space. With increasing energy of the colliding particles, the number of strings grows and they start to overlap, forming clusters. This can introduce a possible dependence of particle production on the initial energy density and on the degree of collectivity achieved in collision processes at ultra-relativistic energies.

We focussed on the phenomenology and model calculations of heavy-ion reactions at LHC energies, extended also to ultra-high-energy proton-proton (pp) and proton-nucleus collisions (pA) [2], mainly to study possible Strong Colour Field (SCF) effects, as well as nuclear effects like shadowing and quenching embedded in our model. Theoretical predictions reported in [2] were obtained prior to LHC p+Pb runs (ALICE, CMS, ATLAS) at $\sqrt{s_{NN}}$ = 5 TeV.

In this study the theoretical results are presented in comparison with currently available data (ALICE, CMS, ATLAS) [4]. The calculations shown here have been updated by considering the same experimental cuts as the data. The experimental observables include multiplicity distributions, transverse momentum distribution, average transverse momentum, nuclear modification factor R_{pPb} , forward and backward asymmetry. The detailed discussions of new results and conclusions are found in [4]. Moreover, comparison with data and other model calculations are also included. Note, the [4] reference is submitted to Int. J. Mod. Phys. E and is attached to this report.

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II. Spectra conditioned by the event shape

As it was described already in a previous report events with high azimuthal isotropy are of a special interest for this analysis. In order to estimate the degree of azimuthal isotropy the global observable directivity was used. This observable is defined as:

$$D^{\pm} = \frac{|\sum_i \vec{p_t^i}|}{\sum_i |\vec{p_t^i}|}\Big|_{\eta^{pos/neg}},$$

As it can be seen from the formula, the events with a high azimuthal isotropy will have a low directivity. For events dominated by jets the directivity increases towards 1.

The fully corrected p_T spectra were obtained by selecting events defined based on their directivity computed for $\eta \in [0,0.8]$, in addition to selection of events based on their multiplicity, which was used until now.

For each multiplicity class (1-6, 7-12, 13-19, 20-28, 29-39, 40-49) three directivity based event classes were defined (0 - 0.3, 0.3 - 0.6 and 0.6 - 1.0). As before, the multiplicity was estimated by summing the global tracks and complementary Inner Tracking System (ITS) standalone tracks and Silicon Pixel Detector (SPD) tracklets in $|\eta|<0.8$.

This study was performed using our local computing farm (NAF) to analyze approximatively $1.4 \cdot 10^7$ events measured by the ALICE experiment at the LHC during the 2010 data taking period.

The selections used for the tracks considered in the analysis and the particle identification procedure were the same as the ones used for the previously reported results, which were obtained using only multiplicity classes.

A similar number of Monte-Carlo simulated events, based on the PYTHIA event generator, which were produced using the specific detector state of that data taking period, were used in order to determine the necessary corrections.

In the case of the spectra defined only by selections in multiplicity, the corrections showed no variation for the different event classes. This has allowed us to use only one set of corrections, which were determined using all the available Monte-Carlo without applying any event selections. However, when one considers also the event shape, in addition to its multiplicity, when defining the event classes, significant differences in the determined corrections are obtained. Therefore, for this study, we have obtained the corrections for each multiplicity-directivity event class and we have applied it to the corresponding raw data.

The results, for the above specified selections in multiplicity and directivity are shown in Figure 1, for pions, kaons and protons. The intermediate directivity class (0.3 - 0.6) is not plotted. For completeness the spectra obtained without any selection in multiplicity (black symbols) and the spectra obtained without any selection in directivity (full squares) are also included in the figure.

In the bottom row the ratios of the spectra obtained with selections in directivity to the spectrum in the corresponding multiplicity class are plotted.

The open crosses in the bottom row are included in order to provide a crosscheck by comparing the already preliminary spectra, obtained using only the selection in multiplicity, with the new results.

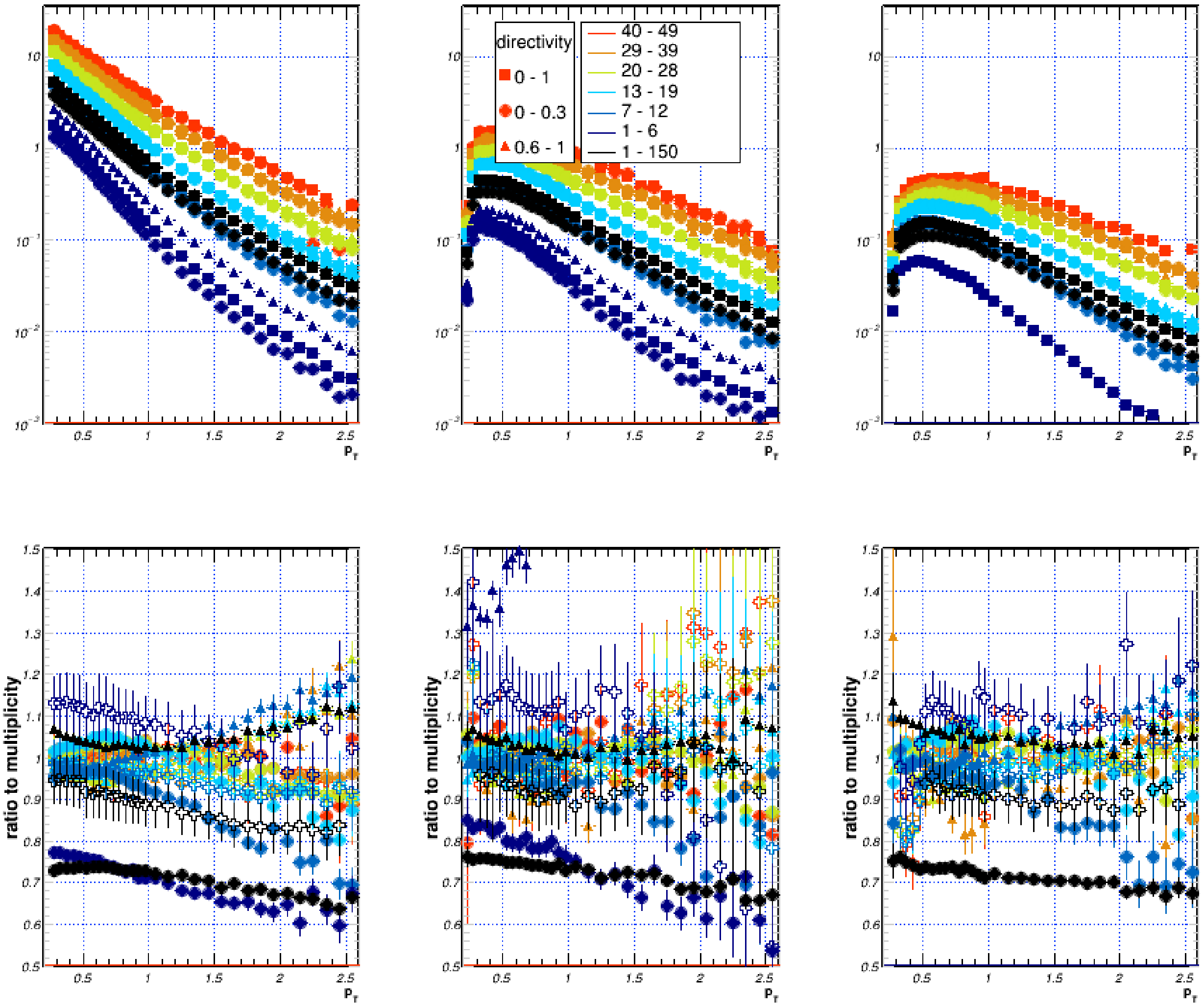


Figure 1

A simultaneous fit of the p_T spectra of π±, K± and p, pbar was done using a well known Boltzmann-Gibbs Blast Wave expression inspired by hydrodynamical models [5]:

$$E\frac{d^3N}{dp^3} \sim f(p_t) = m_t \int_0^R m_T K_1(m_T cosh\rho/T_{fo}) I_0(p_T sinh\rho/T_{fo}) rdr$$

where:

$$m_T = \sqrt{m^2+p_T^2};\ \beta_r(r) = \beta_s(\tfrac{r}{R})^n;\ \rho = tanh^{-1}\beta_r.$$

The fit was done on spectra without directivity constraint, directivity between 0-0.3 and 0.3-0.6 respectively. Two ranges of fit were used, namely a restricted one corresponding to the maximum range in p_T in Pb-Pb spectra where the suppression is not present (established on the model independent representations we have done for comparing the three systems measured at LHC: pp at 7 TeV, p-Pb at 5.02 TeV and Pb-Pb at 2.76 Tev). The larger fit range with K and p up to 3 GeV in

p_T was used in order to see the sensitivity to the fit range. The lower p_T limits were established for pions to reduce the contribution of resonance decays at low p_T and for kaons and protons by the limitation of the analysis.

In Figure 2 and 3 are represented the T_{fo} and n parameters for all the fit cases. Although for the low directivity cut the average transverse expansion velocity is systematically a bit higher than in the other cases and the n parameter a bit lower, in the limit of the parameter errors there is no significant difference for the three cases. In the quality fit plots for all specie in Figure 4 with no directivity cut, 0.3-0.6 cut and 0.0-0.3 respectively, from left to right and increasing multiplicity from top to bottom and from the χ^2 value one can say that the fit quality improves for cuts in directivity and with increasing multiplicity, being slightly better for the lower directivity cut. This trend is expected to be enhanced by applying a directivity condition simultaneously for plus and minus pseudorapidity. But in this case the quality of spectra is highly limited by the available statistics. Nevertheless, from previous studies it seems that the sensitivity of parameters manifests better at higher multiplicity bins which were not yet investigated here. Other event shape selectors are under investigation. The difficulty of these studies consists in applying the efficiency correction which might need a more elaborate procedure of calculation (simultaneous multidimensional correction) than the bin wise correction applied in this study.

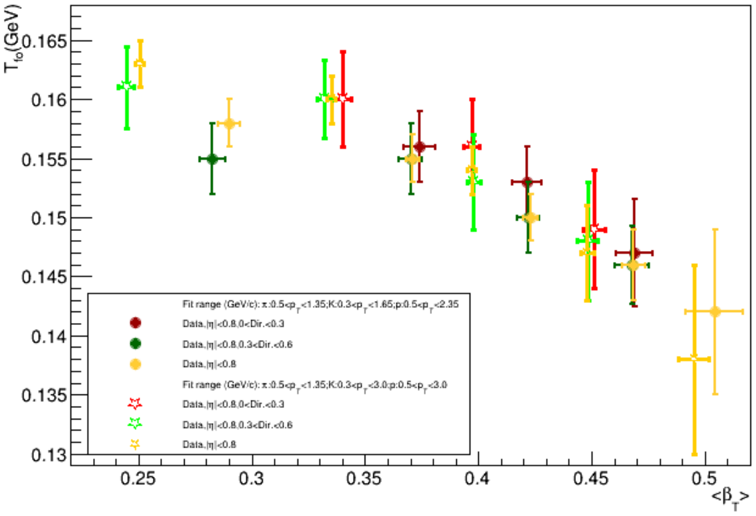


Figure 2

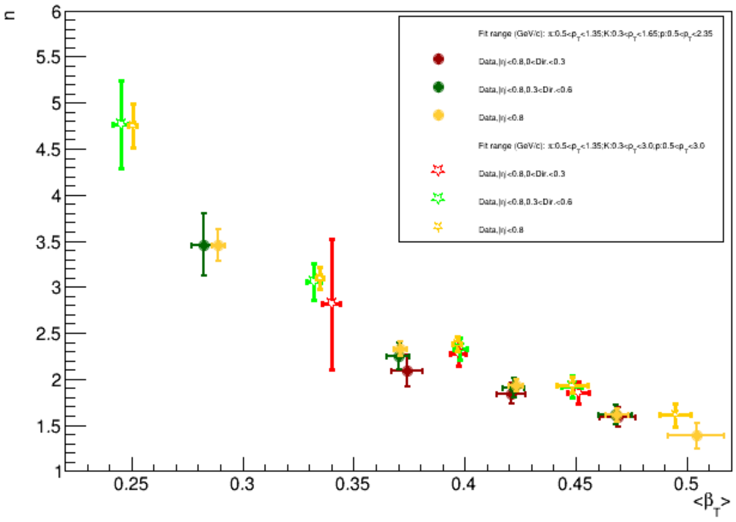
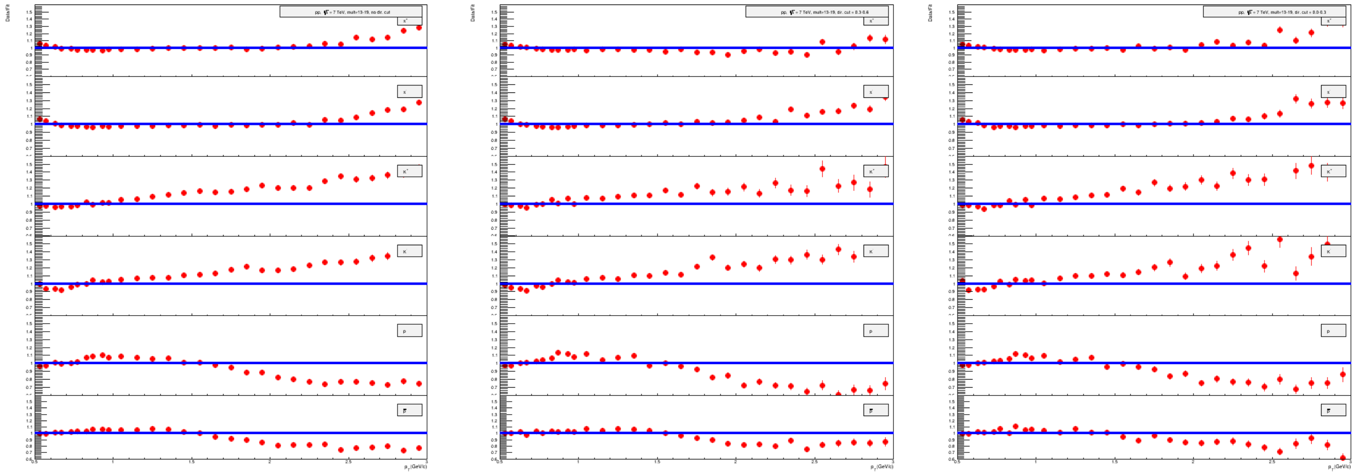


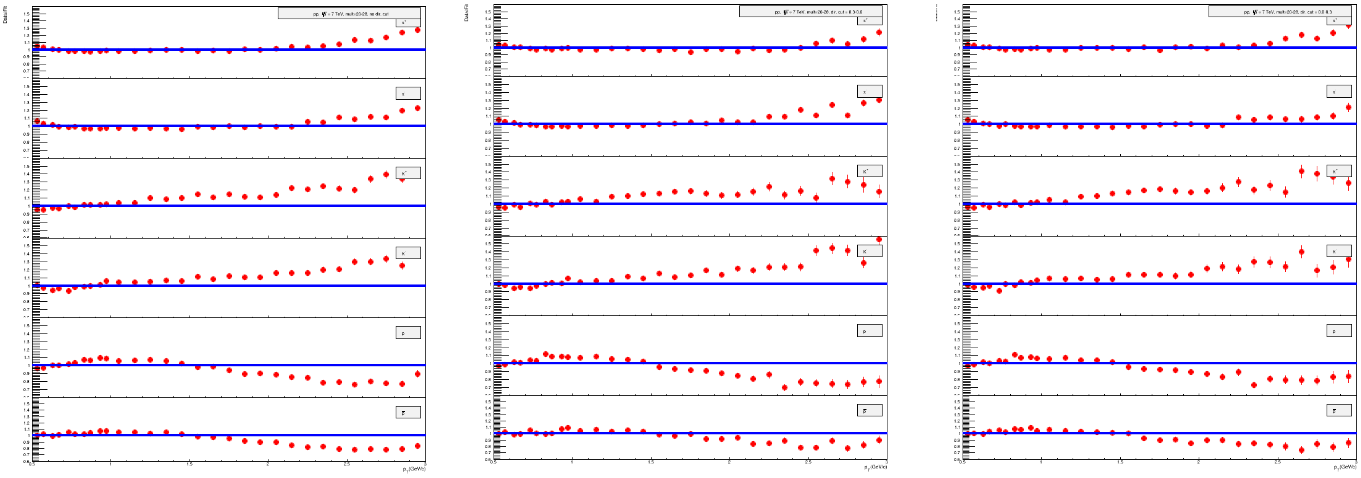
Figure 3

No dir. Cut Dir: 0.3-0.6 Dir: 0-0.3

Mult:13-19



Mult:20-28



Mult:29-39

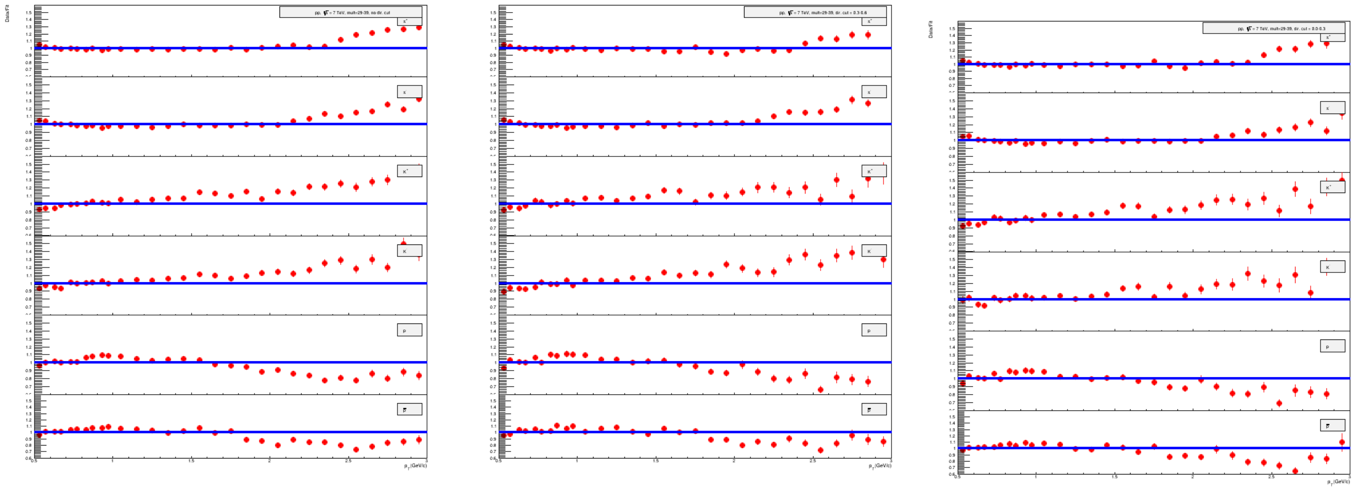


Figure 4

References

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