Soft QCD, minimum bias and diffraction: results from ALICE

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Abstract. We report recent results from the ALICE experiment at the LHC for minimum bias pp collisions. This overview includes results on inelastic cross section, with analysis of single and double diffractive events; the study of hadron production mechanisms, both for inclusive and identified particles; Bose-Einstein correlations; and fluctuations in $\langle p_T \rangle$.

1 Introduction

While the main focus of the ALICE experiment [1] at the LHC is the study of relativistic heavy-ion collisions, ALICE also has a rich and unique proton-proton physics programme, arising from its design. The use of a moderate magnetic field (B=0.5 T) in the barrel region coupled with little material close to the interaction point (7% X_0 perpendicular to the beam direction) allows the study of particle spectra down to very low p_T (~100 MeV/c). In the barrel region ALICE has extensive particle identification capabilities, for charged hadrons via measurements of dE/dx in the inner silicon detector (ITS) and Time Projection Chamber (TPC), in the time-of-flight detector (TOF), and by a devoted transition radiation detector for electrons.

Results summarized here are primarily from data collected in 2010 pp run at $\sqrt{s}$=7 TeV, with a total of 300 million events analyzed, collected with a minimum bias trigger. The trigger requires a hit in the inner silicon detector (SPD) or in either two scintillator counters arrays (VZERO) positioned at z=3.3 m and 0.9 m from the interaction point, close to the beam pipe. The minimum bias trigger essentially requires at least one charged particle anywhere in 8 units of rapidity. Data collected at $\sqrt{s}$=2.76 TeV in 2011 have been also analyzed, with a total of 65 million events. Section 2 present measurements related to inelastic cross section and diffraction, while section 3 reports several measurements studying production mechanisms, taking advantage of particle identification capabilities of the detector. Section 4 presents general events characterstics, obtained by means of Bose-Einstein correlations and studies of fluctuations in $\langle p_T \rangle$. Other proton proton soft QCD topics actively studied in ALICE and not reported here include the study of π^0 yield to constrain the gluon fragmentation function and characterization of underlying event observables. Results related to heavy flavours in proton proton collisions are presented elsewhere in this conference [2].

2 Inelastic cross section and diffraction

To obtain the total inelastic cross section for pp collisions, the cross section of a reference trigger process was measured. This is needed to scale the normalization. The reference cross section has been obtained by means of the Van der Meer scan method, which was applied at $\sqrt{s}$=7 TeV and 2.76 TeV, with the latter scan performed in March 2011. A trigger based on the VZERO detector was used. The cross section for production of at least one charged particle with p_T >0.5 GeV/c in the pesudorapidity region $|\eta|$ <0.8 is in good agreement between LHC experiments and results in the measurement of the total inelastic cross-section shown in Fig. 1, compared with results from ATLAS and CMS. The TOTEM measurement recently published [3] is also in agreement.

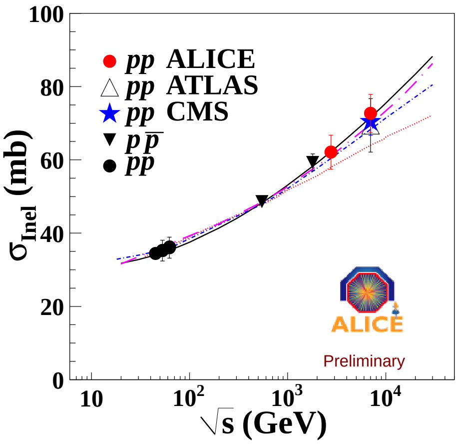

Fig. 1. Inelastic cross-section as a function of collision energy. Data are compared with the predictions of [4] (solid black line), [5] (long dot-dashed pink line), [6] (short dot-dashed blue line) and [7] (dotted red line).

For the analysis of the inelastic cross section ALICE used three subdetectors: the VZERO, the silicon pixel detector (SPD), and the forward multiplicity detector (FMD), an array of silicon sensors at large rapidity. With the addition of the FMD the pseudorapidity coverage is -3.7< η <5.1. Due to the geometry of the detectors used it was possible to define one and two-arm triggers and to study the pseudorapidity gap pattern of the tracks obtained from the event vertex and a hit in SPD, VZERO or FMD. With this technique ALICE measured the relative fraction of single diffractive (SD) and double diffractive (DD) processes. Since the non-diffracted proton in SD processes is outside

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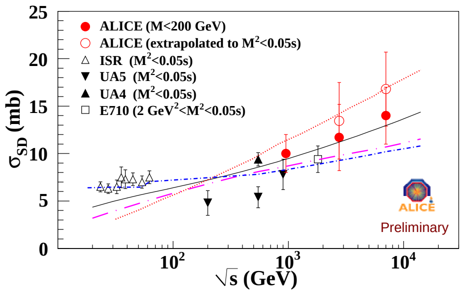

Fig. 2. Single diffractive cross-section as a function of collision energy. Predictions are from the same models as in Fig. 1

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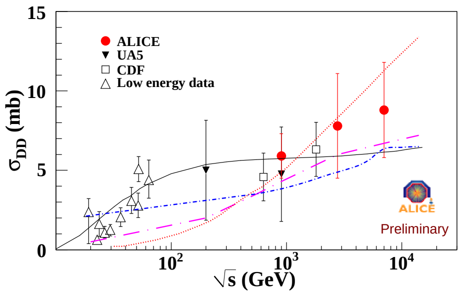

Fig. 3. Double diffractive cross-section as a function of collision energy. Predictions are from the same models as in Fig. 1

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detector acceptance in ALICE, the measurement is model dependent. PYTHIA and PHOJET Monte Carlo generators were tuned using the model described in [4] to provide the SD cross-section dependence on the diffracted mass.

The result for SD and DD cross section are shown in Fig. 2 and 3, compared with previous measurements at lower center of mass energies. There is good agreement between ALICE and UA5 at $\sqrt{s}$=900 GeV. Within the errors, the theoretical models broadly describe the data, though they all have a difficulty to fit the data simultaneously at lower and higher energies, especially for DD processes. The ratio of σ_{SD} and σ_{DD} with respect to the inelastic cross sections is constant within the uncertainty. Further details can be found in [8].

3 Production mechanisms

3.1 Inclusive production

Charged multiplicity and inclusive spectra of charged particles have been extensively studied by ALICE, which has reported results at different collision energies ($\sqrt{s}$=0.9 [9], 2.36 [9], and 7 TeV [10]. During 2011 a low-energy run at $\sqrt{s}$=2.76 TeV was undertaken to provide accurate normalization for Pb-Pb data which were collected at the same center of mass energy. The observed charged particle p_T spectrum is shown in Fig. 4, together with previous measurements. A modified Hagedorn function successfully fits the data, with a p_T^{-n} power law at high p_T (above 3 GeV/c). Note the low p_T reach of the detector, which has been used to find discrepancies with pre-LHC Monte Carlo tunes below 0.5 GeV/c [9].

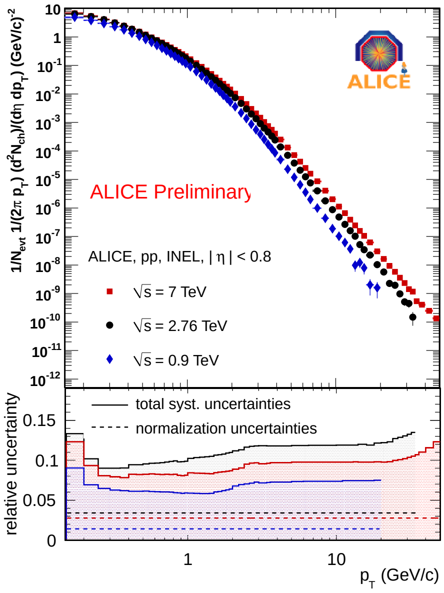

Fig. 4. Charged particle transverse momentum spectrum (in the range 0.15< p_T <50 GeV/c) measured in pp collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV with the total systematic uncertainties as well as the overall normalization uncertainty.

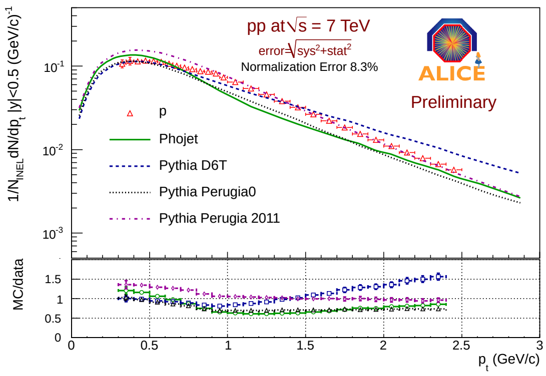

Fig. 5. Measured proton spectra compared with pre-LHC and more recent MC tunes.

3.2 Identified particle spectra

The ALICE experiment, using its particle identification capabilities, provided preliminary results for identified particles spectra for pions, kaons and protons. These are based on individual or combined measurements made by its ITS, TPC and TOF detectors in various p_T ranges. A Lévy-Tsallis function fits the data and allows to extrapolate the yield down to p_T=0. Comparisons are made with several Monte Carlo codes. PYTHIA tune Perugia 2011 shows good agreements with kaons and overestimates the pion yield, while the proton description is in good agreement with data above 0.7 GeV as seen in Fig. 5. The study of particle ratios (shown in Fig. 6) challenges Monte Carlo tunes. No discernible energy dependence was obtained for the particle ratios, when compared with existing measurements made by PHENIX, STAR, E735 and UA5, while the $\langle p_T \rangle$ showed a modest increase with energy for pions, kaons and protons, consistently with a a linear expectation from a simple linear scaling.

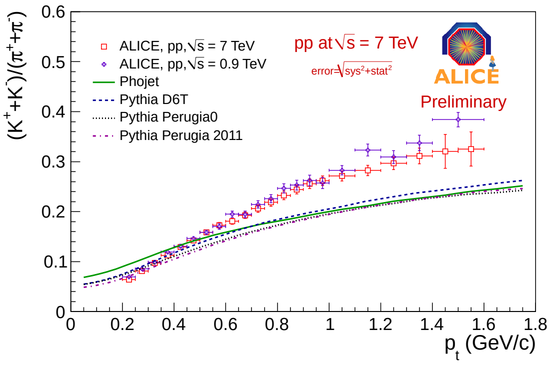

Fig. 6. Kaon to pion ratio compared to various MC generators.

3.3 Strange and multi-strange hadrons

Particle identification methods were combined with weak decays topological techniques and invariant mass analyses to identify and study strange and multi-strange hadrons. PYTHIA tune Perugia 2011 provides good predictions for kaons, but the agreement is not yet satisfactory for $\Xi^{\pm}$ and $\Omega^{\pm}$, in particular in the intermediate (1-5 GeV/c) p_T region as seen in Fig. 7. The agreement at high p_T (6-9 GeV/c) is good for $\Xi^{\pm}$, but further statistics is needed for $\Omega^{\pm}$. It should be noted that the Perugia 2011 tune optimizes strangeness production using early LHC measurements, including from ALICE. However, it underestimates the production of strange resonances, as Σ^{*} and K^{*0}, while various MC tunes shows better agreement with ϕ, especially PHOJET. The differences are mainly related to baryons productions, suggesting the possible presence of other hadronization mechanisms, like quark coalescence, which have been proposed to explain the enhancement of the yield ratio Λ/K^0_S reported in heavy ions collisions.

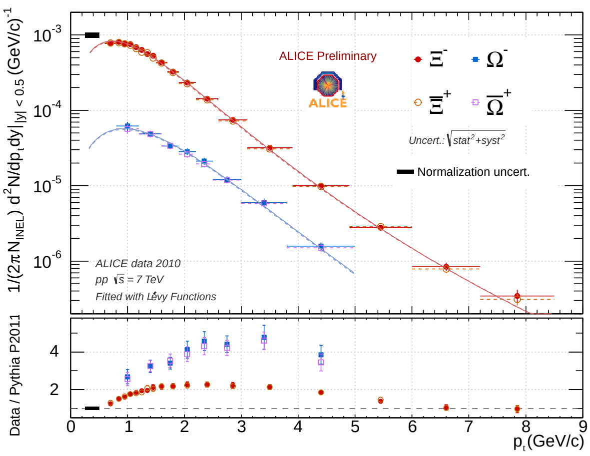

Fig. 7. $\Omega^{\pm}$ and $\Xi^{\pm}$ spectra measured at ALICE, compared with Perugia 2011 tune.

4 Bose-Einstein correlations and fluctuations

Bose-Einstein correlations of identical boson pairs (pions or kaons) have been studied by ALICE. The extraction of Hanbury-Brown Twiss radii, and their dependence on various observables, may shed light on the spatial scale of the emitting source. This femtoscopic analysis in pp collisions is able to obtain precise data on 'elementary' systems. High-multiplicity pp collisions at the LHC have particles densities comparable to that measured at RHIC in heavy ions, and a direct comparison of the freeze-out sizes of systems with very different initial states is therefore possible.

The correlation function for identical pion pairs is defined as $C(\mathbf{q}) = A(\mathbf{q})/B(\mathbf{q})$, where $A(\mathbf{q})$ is the measured two-pion distribution of pair momentum difference $\mathbf{q} = \mathbf{p}_2 - \mathbf{p}_1$, and $B(\mathbf{q})$ is the equivalent distribution obtained by using pairs of particles coming from different events. A quantitative analysis of the correlation functions allows the extraction of the sizes of the emitting source (HBT radii) R^G_{long}, R^G_{out} and R^G_{side}, which are oriented along the beam axis, along the pair transverse momentum k_T and perpendicular to the other two. Full details are described in [11].

Fig. 8 shows dependence of the HBT radii on the pair transverse momentum, for various event multiplicities. We observe R^G_{out} and R^G_{side} decrease with k_T at large multiplicities, while R^G_{long} falls at all multiplicities. In heavy ions collisions the decrease with k_T is a signature of collective motion. While the observed behaviour in pp is qualitatively similar, the difference seen in particular for the transverse radii shows that a radial flow interpretation cannot be easily inferred.

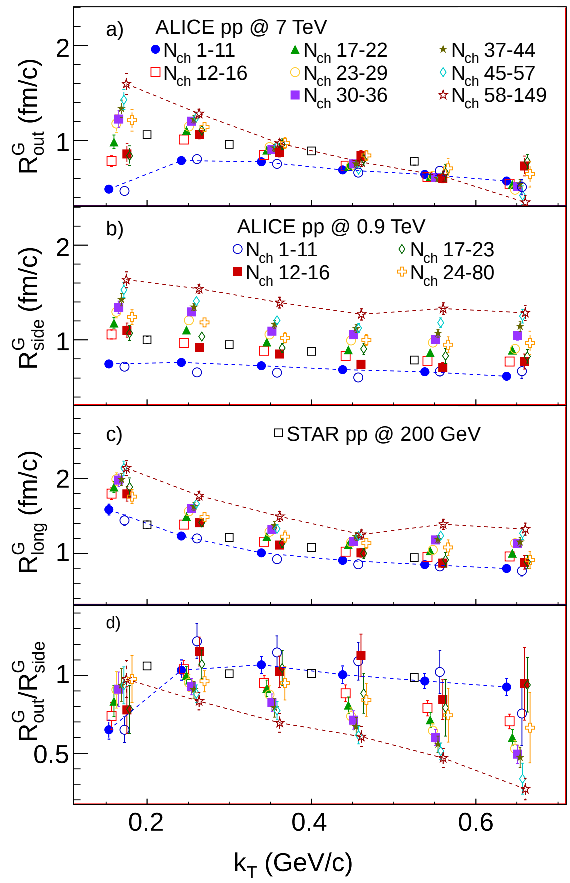

Fig. 8. HBT radii dependence on k_T for different multiplicities, with ALICE data at $\sqrt{s}$=0.9 TeV and $\sqrt{s}$=7 TeV.

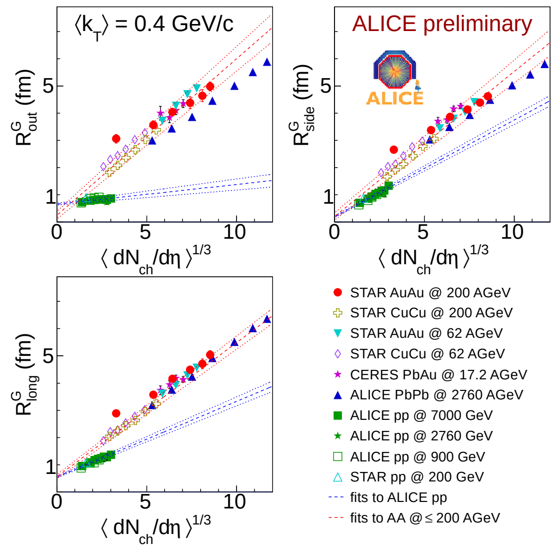

Fig. 9. HBT radii as a function of charged pseudorapidity density. Results from pp and heavy ions collisions are compared.

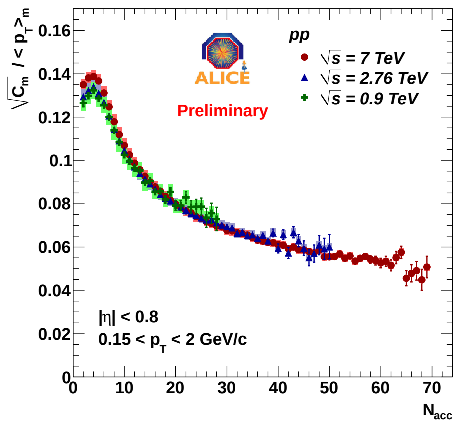

Fig. 10. Relative fluctuations in ALICE at different center of mass energy as a function of accepted tracks multiplicity

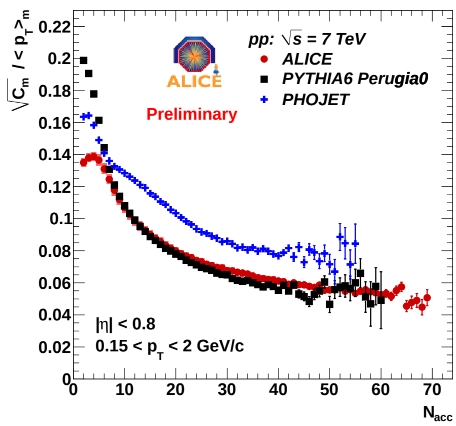

Fig. 11. Relative fluctuations: comparison of ALICE pp data with MC generators.

A linear dependence with $\langle dN/d\eta \rangle^{1/3}$ is expected for the HBT radii. Fig. 9 shows the direct comparison between elementary and 'compound' systems: different slopes and offsets for pp and heavy ions are observed and the size of the pp emitting source is ≈ 1 fm. The linear fits show qualitative agreement with hydrodynamical models, though the trends inferred by other lower energies heavy ions data are not in agreement with R^G_{out}.

Global event characterization was also studied measuring fluctuations of $\langle p_T \rangle$ in pp collisions. This observable is expected to be dominated by resonance decays, Bose-Einstein correlations and mini-jets. We study fluctuations of $\langle p_T \rangle$ event-by-event over all tracks pairs, via a particle correlator C_m defined as a function of the number of accepted tracks. For purely statistical fluctuations this observable is expected to have a null value. Once the values are normalized to the $\langle p_T \rangle$ which is different at different collision energies, the relative fluctuations appear to be universal at LHC (except at small multiplicity) and not null, as seen in Fig. 10. Fig.11 shows comparisons with Monte Carlo at $\sqrt{s}$=7 TeV: PYTHIA Perugia-0 tune describes the data well except for low multiplicity, while PHOJET significantly overestimates the observed pattern.

5 Conclusions

In these proceedings we have reported an overview of ALICE results in pp collisions, primarily using the data sample collected in 2010. Refined analyses are expected including the 2011 statistics. While various measurements taken in pp collisions are a necessary baseline for its heavy-ions physics programme, a rich proton-proton physics programme has been developed by ALICE exploiting its detector capabilities, which are particularly relevant for soft QCD studies.

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