Cluster properties from two-particle angular correlations in pp collisions at CMS

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Results on two-particle angular correlations for charged particles are presented for proton-proton collisions data at $\sqrt{s} = 0.9, 2.36$ and 7 TeV, collected with the CMS experiment. The results are quantified in terms of a simple independent cluster parametrization and compared to previous results and to the Monte Carlo model in PYTHIA.

1 Introduction

A proton-proton collision at the LHC is a complicated process, where the hard interaction is described by perturbative QCD, but the subsequent final state radiation, hadronization process and decay and in addition multiparton interactions have to be modelled by the Monte Carlo (MC) generators. Also multiparticle correlations in the event have been studied and compared to models, in a wide range of center-of-mass (c.m.) energies, in pp, $p\bar{p}$ and heavy-ion collisions.

In particular two-particle correlations have been extracted as a function of the relative pseudorapidity ($\Delta\eta$, where $\eta = -\ln(\tan(\theta/2))$ and θ is the polar angle with respect to the beam direction) and azimuthal angle ($\Delta\phi$) between the particles. The resulting two-dimensional (2-D) distribution in $\Delta\eta$-$\Delta\phi$ reveals a complicated structure, with a Gaussian peak around $\Delta\eta \simeq 0$ (see for example Ref. [1, 2, 3, 4, 5]). A simple ansatz, the Independent Cluster Model (ICM) has been used by the experiments to parametrize the correlations. In this ansatz, the clusters are assumed to be emitted independently and then decay isotropically in their own rest frame into the observed hadrons. The observed correlation strength and extent in relative pseudorapidity can be parametrized by the cluster "size" (the average number of particles into which a cluster decays) and "width" (the spread of the daughter particles in pseudorapidity).

Results from the CMS experiment were obtained in the early minimum bias data taken at $\sqrt{s} = 0.9, 2.36$ and 7 TeV [6]. The CMS tracker [7], with a coverage in pseudorapidity in the range $-2.4 < \eta < 2.4$ and full coverage in azimuth, is well suited to measure this type of correlations. In addition the tracks were selected for this analysis down to very low transverse momenta, $p_T > 0.1$ GeV/c. The trigger used for these data preferentially selected non-single-diffractive (NSD) events.

2 Analysis Technique

The approach used here is very similar to the one adopted by the previous experiments at ISR and RHIC [2, 4]. The 2-D function for the angular correlations for each pair of particles is defined as

$$R(\Delta\eta, \Delta\phi) = < (N-1)(\frac{S_N(\Delta\eta, \Delta\phi)}{B_N(\Delta\eta, \Delta\phi)} - 1) >_{\text{N}}, \quad (1)$$

where S_N and B_N are the signal and background distributions, respectively, and N is the charged track multiplicity in the event. The signal and background distributions were calculated as:

$$S_N(\Delta\eta, \Delta\phi) = \frac{1}{N(N-1)} \frac{d^2 N^{\text{signal}}}{d\Delta\eta\Delta\phi}, \qquad B_N(\Delta\eta, \Delta\phi) = \frac{1}{N^2} \frac{d^2 N^{\text{mixed}}}{d\Delta\eta\Delta\phi}, \quad (2)$$

where $\Delta\eta = \eta_1 - \eta_2$ and $\Delta\phi = \phi_1 - \phi_2$ for each pair of charged particles 1,2 in the event for the signal, while in the combinatorial background the distribution is calculated from two particles in two different events. The two events were randomly mixed in the same intervals of multiplicity and vertex longitudinal position, in order to correctly take into account the different acceptance as a function of these two variables. The ratio in Eq. (1) was also calculated in each multiplicity bin, and then averaged over all multiplicities. In the ratio, many systematic uncertainties common to the signal and background cancel out.

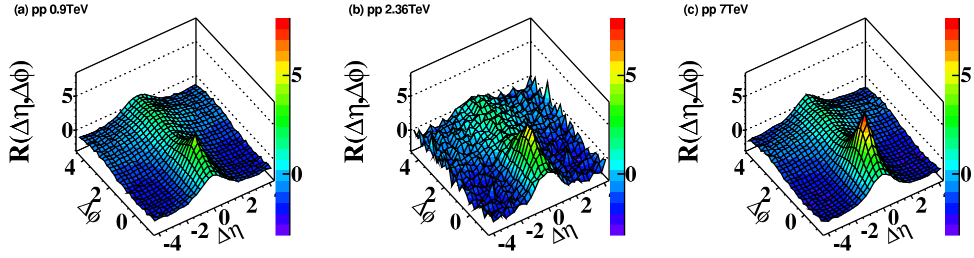

Figure 1: The 2-D two-particle correlation function $R(\Delta\eta, \Delta\phi)$ for the CMS data at the three c.m. energies.

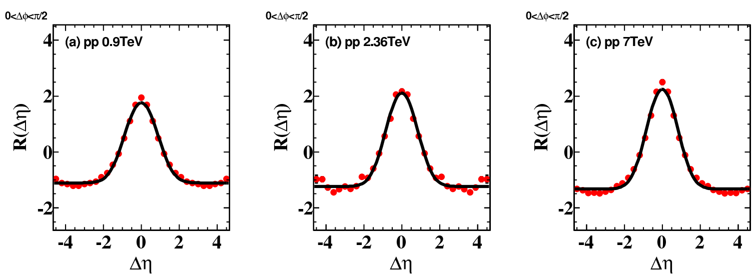

Figure 2: The two-particle correlation function $R(\Delta\eta)$ for the CMS data at the three c.m. energies. The line corresponds to the fit described in the text.

The distributions of $R(\Delta\eta, \Delta\phi)$ at the three c.m. energies are shown for the CMS data in Fig 1. One can see two main features. The first one is that the correlations present a sharp peak around $\Delta\eta, \Delta\phi \simeq 0$ and a one broader around $\Delta\eta \simeq 0, \Delta\phi \simeq \pi$, where the first one corresponds to the contribution of higher p_T clusters (hard processes like jets), while the second one to lower

p_T, soft QCD, physical objects. The second feature is that the correlations become stronger as the c.m. energy increases.

3 Results

In order to study these correlations further, the 2-D correlation function was reduced to a 1-D function in $\Delta\eta$ by integrating the signal and background distributions over $\Delta\phi$. The resulting correlation function $R(\Delta\eta)$ is shown in Fig. 2, showing the typical Gaussian shape of these correlations.

The 1-D correlation function can then be parametrized, as done by previous experiments, by:

$$R(\Delta\eta) = (K_{\text{eff}} - 1)\left[\frac{\Gamma(\Delta\eta)}{B(\Delta\eta)} - 1\right], \quad \Gamma(\Delta\eta) \propto \exp\left(-\frac{(\Delta\eta)^2}{4\delta^2}\right). \tag{3}$$

In the context of the ICM, K_{eff} can be interpreted as the average cluster size or multiplicity, while δ gives information on the cluster width in $\Delta\eta$. The two parameters have then been determined from a fit to the data with the function of Eq. (3), as shown in Fig. 3. The cluster size increases with the c.m. energy and on average every 2-3 particles are produced correlated, at a distance of $\Delta\eta \simeq 0.5$. The width δ remains constant with $\sqrt{s}$. The MC model PYTHIA [8] reproduces the width and the trend with $\sqrt{s}$ for K_{eff}, but fails to predict the strength of the correlation. Different tunes in PYTHIA for multiparton interactions and the Bose-Einstein correlations cause marginal effects on the results. The HERWIG [9] MC predicts a shape for the correlation function which is very different from the one in the data.

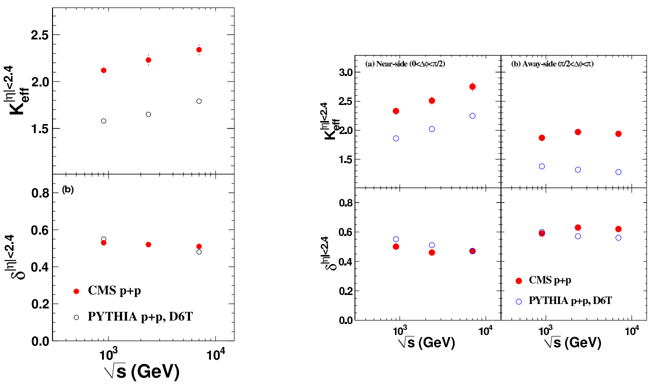

Figure 3: The two parameters K_{eff} and δ determined from a fit to the CMS data at the three c.m. energies. The left figure indicates the result over the whole $\Delta\phi$ range, while the right one is the result for the near- and away-side. The error bars indicate the systematic uncertainties, which are due to the tracking and event selection efficiencies and the model dependence of the corrections.

The fit was also repeated for two different ranges in $\Delta\phi$, one corresponding to the near-side, where high-p_T jets contribute, one to the away-side, for lower p_T physics. As can be seen in Fig. 3, the away-side cluster size shows no increase, while the contribution for high p_T jets increases with the c.m. energy.

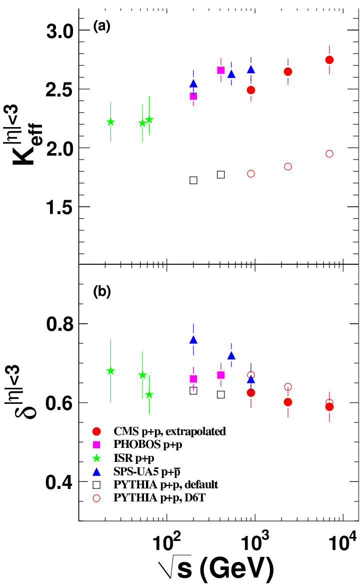

Figure 4: The two parameters $K_{\rm eff}$ and δ for the CMS data and previous results from other experiments. For this comparison the parameters have been extrapolated to the kinematic region $p_T > 0$ and $|\eta| < 3$ for the charged tracks, as explained in Ref. [6].

4 Conclusions

The results presented here are at the highest c.m. energy reached until now. It is then interesting to compare them to lowest energy data results, in pp, p$\bar{\rm p}$ and also to RHIC results. Heavy-ion experiments are particularly interesting, as this type of correlations could be modified in presence of a quark gluon plasma, so these studies are preparing the field of heavy-ion studies at the LHC. This comparison is shown in Fig. 4, where the CMS data have been extrapolated to the same kinematical region of the other experiments. The CMS result on $K_{\rm eff}$ at 0.9 TeV is lower, but compatible, with the UA5 point. The trends with $\sqrt{s}$ seen in the CMS data alone, both in the cluster size and width, are strengthened by this comparison.

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