Scientific Summary of CMS Paper

Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions

ABSTRACT

Results on two-particle angular correlations for charged particles emitted in proton-proton collisions at center-of-mass energies of 0.9, 2.36, and 7 TeV are presented, using data collected with the CMS detector over a broad range of pseudorapidity ($\eta$) and azimuthal angle ($\phi$). Short-range correlations in $\Delta \eta$, which are studied in minimum bias events, are characterized using a simple “independent cluster” parametrization in order to quantify their strength (cluster size) and their extent in $\eta$ (cluster decay width). Long-range azimuthal correlations are studied differentially as a function of charged particle multiplicity and particle transverse momentum using a 980 nb$^{-1}$ data set at 7 TeV. In high multiplicity events, a pronounced structure emerges in the two-dimensional correlation function for particle pairs with intermediate $p_T$ of 1–3 GeV/$c$, $2.0 < |\Delta \eta| < 4.8$ and $\Delta \phi \approx 0$. This is the first observation of such a long-range, near-side feature in two-particle correlation functions in $pp$ or $p\bar{p}$ collisions.

The full paper can be found at http://cms.web.cern.ch/cms/News/2010/QCD-10-002/
1 Scientific Summary

The paper “Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions” presents measurements of two-particle angular correlations of charged particles emitted in proton-proton (pp) collisions at center of mass energies (\(\sqrt{s}\)) of 0.9, 2.36 and 7 TeV. This summary focusses on studies at the highest energy, where measurements of long-range correlations can be expected to exhibit new collective effects due to the high particle densities reached in these collisions.

In current pp MC event generators, the only source of long-range correlations are momentum conservation and away-side (\(\Delta\phi \sim \pi\)) correlations from back-to-back production of jets. The data taken at the highest LHC energy allow to study a new regime and could well show novel features of multi-particle production in pp collisions. The presently used MC generators are not necessarily complete or well tuned for this new energy regime. Moreover measurements at the Relativistic Heavy Ion Collider (RHIC) have significant modifications of the correlation structure for particle transverse momenta (\(p_T < 5\) GeV/c). These correlations have been interpreted as novel initial state effects and as results of a hydrodynamic expansion of a Quark-Gluon Plasma formed in these collisions. Since the particle densities produced in the highest multiplicity pp collisions at LHC energies begin to approach those in high energy collisions of smaller nuclei such as copper, it is natural to search for the possible emergence of new features in the two-particle correlation function from high multiplicity pp events.

For this study, a dedicated high multiplicity trigger was implemented in the two levels of the CMS trigger system. This trigger uses a combination of the total transverse energy in the CMS calorimeters at the Level-1 trigger and counting of particle tracks in the pixel detector at the High Level trigger. The total accepted integrated luminosity sampled by the high multiplicity trigger for this paper was 980 nb\(^{-1}\).

In this analysis, angular correlations have been studied using two-dimensional \(\Delta\eta - \Delta\phi\) correlation functions. Here \(\Delta\eta\) is the difference in pseudorapidity \(\eta\) between the two particles and \(\Delta\phi\) is their difference in azimuthal angle \(\phi\). The charged two-particle correlation function in terms of \(\Delta\eta\) and \(\Delta\phi\) is defined as follows:

\[
R(\Delta\eta, \Delta\phi) = \frac{\langle (N-1) S_N(\Delta\eta, \Delta\phi) - 1 \rangle B_N(\Delta\eta, \Delta\phi) \rangle_N}{N}
\]

where \(S_N\) and \(B_N\) are the signal and background distributions, respectively. The background distribution was constructed by pairing particles from different randomly selected events.

The search for novel long-range azimuthal correlations was performed in bins of event multiplicity and particle transverse momentum for the high multiplicity data set. Figure 1 compares 2-D two-particle correlation functions for minimum bias and high multiplicity events, for both inclusive particles and for particles in an intermediate \(p_T\) bin. For minimum bias events and inclusive particles with \(p_T > 0.1\) GeV/c, the region at \(\Delta\eta \approx 0\) shows a typical structure also seen in lower energy collisions, which is often parametrized in terms of particle emission from “clusters”. Also visible is the contribution from jet-like particle production near \((\Delta\eta, \Delta\phi) \approx (0,0)\) due to near-side jet fragmentation and a broad elongated ridge around \(\Delta\phi \sim \pi\) due to fragmentation of back-to-back jets. The shallow minimum at \(\Delta\phi \sim 0\) at large \(|\Delta\eta|\) is a consequence of momentum conservation. For the intermediate \(p_T\) region of 1.0 GeV/c < \(p_T < 3.0\) GeV/c the enhanced contribution of jet fragmentation to particle production at higher \(p_T\) dominates the correlation function.

For \(p_T\)-integrated two-particle correlations in high multiplicity events (\(N_{\text{offline}}^{\text{trk}} > 110\), Fig. 1c),
most correlation structures are similar to those for minimum bias events. The cut on high multiplicity enhances the relative contribution of high $p_T$ jets which fragment into a large number of particles. (compare Fig. 1b and Fig. 1c).

In the intermediate $p_T$ range in high multiplicity events shown in Fig. 1d, an unexpected effect is observed in the data. A clear and significant “ridge”-like structure emerges at $\Delta \phi \sim 0$ with a $\Delta \eta$ extent of at least 4 units. This is a novel feature of the data which has never been seen in two-particle correlation functions in $pp$ or $p\bar{p}$ collisions. An identical analysis of simulated data from models like PYTHIA6, PYTHIA8, Herwig or Madgraph does not show such an effect.

The 2-D correlation functions were also obtained in four bins of charged particle multiplicity and four bins of particle transverse momentum and then projected onto 1-D $\Delta \phi$ correlations for $2.0 < |\Delta \eta| < 4.8$. In Fig. 2 CMS data are shown as solid markers and the lines show PYTHIA8 results. All panels show the away-side jet contribution at $\Delta \phi \approx \pi$. In addition, for high multiplicity bins of $N \sim 90$ in the intermediate $p_T$-region, $1 < p_T < 3$ GeV/c, a second local maximum near $\Delta \phi \sim 0$ is clearly observed. In addition to a quantitative discrepancy in modeling the away-side yields, PYTHIA8 qualitatively fails to reproduce the novel local maximum near $\Delta \phi \sim 0$ in the high multiplicity bins. It appears that, within the present implementation in the MC models, neither soft particle production from string fragmentation nor the contribu-
The features of the near-side ridge are reminiscent of those of collective effects observed in relativistic nucleus-nucleus collisions. However, further studies are needed to elucidate the nature of this new correlation structure and to explore its possible connection to the phenomena seen in other collision systems. The CMS detector is an ideal instrument for these additional studies. Of particular importance are the large acceptance and calorimetric coverage, which will allow an investigation of the connection of the observed correlations to jet-like particle production. The calorimeters will also allow a quantitative study of the correlations in the $\pi^0$ channel, while higher order correlation measurements like three-particle correlations will be able to discriminate between different hypothesis for the origin of the correlations. With this observation, a new testing ground for QCD under extreme conditions has become available to experimenters.