PROCEEDINGS OF SCIENCE

Bose–Einstein Correlations in pp Collisions at $\sqrt{s} = 0.9$ and 7 TeV

PoS(WPCF2011)015

Luca Perrozzi for the CMS Collaboration*
Universita' di Padova & INFN Padova
E-mail: perrozzi@cern.ch

Bose–Einstein correlations between identical particles are measured in samples of proton-proton collisions at 0.9 and 7 TeV centre-of-mass energies, recorded by the CMS detector at the LHC. The signal is observed in the form of an enhancement of number of pairs of same-sign charged particles with small relative momentum. The dependence of this enhancement on kinematic and topological features of the event is studied. The first observation in pp interactions of anticorrelations between same-sign charged particles in the region of relative momenta higher than those in the signal region are discussed.

The Seventh Workshop on Particle Correlations and Femtoscopy
September 20th to 24th, 2011
The University of Tokyo, Japan

*Speaker.

Interferometry of identical bosons is a powerful tool to investigate the space-time structure of sources emitting particles produced at different center-of-mass energies and from different initial systems [1]. The effect manifests itself as a constructive interference at low values of the relative momentum of the pair, which can be expressed in a Lorentz-invariant form as $Q = \sqrt{-(p_1 - p_2)^2} = \sqrt{M^2 - 4m_\pi^2}$, where M is the invariant mass of the two particles, assumed to be pions with mass m_π. Experimentally, the Bose–Einstein correlation (BEC) function is constructed as the ratio $R(Q) = (\mathrm{d}N/\mathrm{d}Q)/(\mathrm{d}N_{\mathrm{ref}}/\mathrm{d}Q)$ of the Q distributions for pairs of identical bosons in the same event, and for pairs of particles in a reference sample not containing the BEC effect. In the measurements discussed here a mixed reference sample was used, which is the most commonly adopted in femtoscopic analyses. Such sample was constructed by pairing equally charged particles from different events that have similar charged-particle multiplicities in the same pseudorapidity regions.

The CMS detector is described in detail in Ref. [2]. Its inner tracking system is the most relevant part for the present analysis. It is composed of a silicon pixel detector with three barrel layers at radii between 4.4 and 10.2 cm, and a silicon strip tracker with 10 barrel layers extending outwards to a radius of 1.1 m. Each system is completed by two endcaps, extending the acceptance up to a pseudorapidity $|\eta| = 2.5$. A more complete description of the experimental acceptance and cuts adopted in this analysis is in [3, 4].

The analysis presented here correspond to the $\sqrt{s} = 0.9$ and 7 TeV data taken during low-intensity runs, with 51.7 million tracks selected in the total of 2.7 million events. All pairs of same-sign charged particles with Q between 0.02 and 2 GeV (adopting $\hbar = c = 1$) are used for the measurement. The Q resolution in the signal region is better than 10 MeV. The effect of Coulomb interactions between charged particles is pairwise corrected using the Gamow factor [5].

The correlation function represented by the ratio $R(Q)$ is frequently fitted by superimposing the parameterization

$$R(Qr) = C\,[1 + \lambda\Omega(Qr)] \cdot (1 + \delta Q). \tag{1}$$

When space-time and momentum correlations in the system formed in the collisions are not significant, $\Omega(Qr)$ is given by the modulus square of a Fourier transform of the space-time region emitting bosons with overlapping wave functions, characterized by an effective size r. A Gaussian function, $\Omega(Qr) = e^{-(Qr)^2}$, or an exponential form, $\Omega(Qr) = e^{-Qr}$, are commonly adopted. Some deviations from the idealized picture are taken into account in Eq.(1) by the intercept parameter λ, reflecting the BEC strength for incoherent boson emission from independent sources, the δ factor, for accounting for long-range momentum correlations, and C is a normalization factor. Furthermore, for reducing possible biases in the construction of the reference sample, a double ratio $\mathscr{R}(Q) = \frac{R}{R_{\mathrm{MC}}} = \left(\frac{\mathrm{d}N/\mathrm{d}Q}{\mathrm{d}N_{\mathrm{ref}}/\mathrm{d}Q}\right) \Big/ \left(\frac{\mathrm{d}N_{\mathrm{MC}}/\mathrm{d}Q}{\mathrm{d}N_{\mathrm{MC,\,ref}}/\mathrm{d}Q}\right)$ is defined, where the subscripts "MC" and "MC,ref" refer to the corresponding distributions from the Monte Carlo simulations, generated without BEC effects. More details can be found in Ref. [3, 4].

The double ratio is shown in Fig.1(a) for $Q > 0.02$ GeV, with the correlation function fit of the exponential parameterization, $\Omega(Qr) = e^{-Qr}$, in $\mathscr{R}(Q) = R(Qr)$ from Eq.(1). The fitted values correspond to $r(\mathrm{fm}) = 1.89 \pm 0.02(\mathrm{stat}) \pm 0.19(\mathrm{syst})$, and $\lambda = 0.618 \pm 0.009(\mathrm{stat}) \pm 0.039(\mathrm{syst})$, which are strongly correlated, with correlation coefficients of about 86%. The Gaussian parameterizations, $\Omega(Qr) = e^{-(Qr)^2}$, used in several experiments was also analysed, but provided values of $\chi^2/N_{\mathrm{dof}} > 9$.

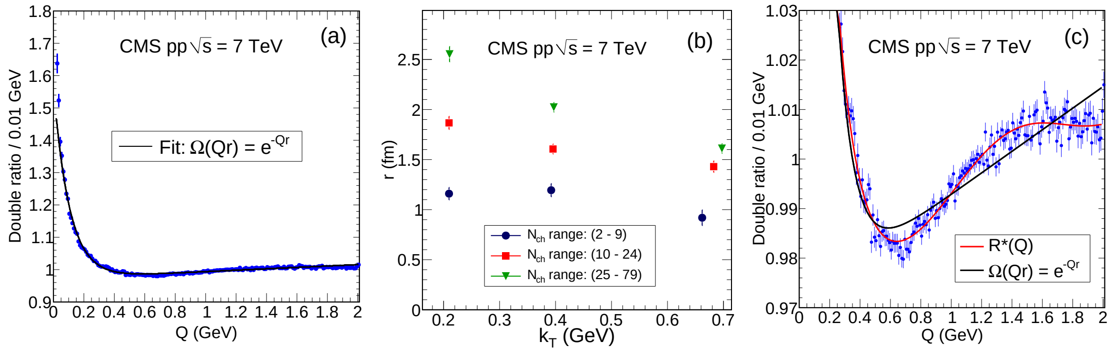

Figure 1: Data points for the double ratio are shown in (a), together with the fit given by the exponential parameterization in Eq.(1). Part (b) shows the behavior of the r parameter obtained with this $\Omega(Qr) = e^{-Qr}$ form as a function of k_T for three bins in $N_{\rm ch}$. The plot in (c) shows the anticorrelation structure in the double ratio [note the zoomed ordinate axis with respect to the plot of part (a)]. The uncertainties in the plots are statistical only.

In Fig.1(b) results for the r parameter fitted with $\Omega(Qr) = e^{-Qr}$ in Eq.(1) is shown as a function of the average transverse momentum of the pair, $k_T = (k_{1_T} + k_{2_T})/2$, for three different bins of charged multiplicity, $N_{\rm ch}$. The points are presented at the position corresponding to the mean value of k_T in the considered interval of $N_{\rm ch}$. The effective radius, r, is observed to steadly increase with $N_{\rm ch}$. It can be seen that r is approximately independent of k_T in the smaller multiplicity range, but clearly decreases with increase k_T for larger charged multiplicity events. A dependence on $k_{\rm T}$ has been observed at the SPS, at the Tevatron and at RHIC [6], where it is associated with the system collective behavior. Similar results in pp collisions are seen by ALICE Collaboration [7].

Althought the parameterization $\mathscr{R}(Qr)$ with the exponential form, $\Omega(Qr) = e^{-Qr}$, in Eq.(1) could describe the overall behavior of the data, it resulted in $\chi^2/N_{\rm dof} = 739/194$ for the $\sqrt{s} = 7$ TeV data and $\chi^2/N_{\rm dof} = 485/194$ for the $\sqrt{s} = 0.9$ TeV data (more details in Ref. [4]). This poor quality fit is originated in an anticorrelation (dip with $\mathscr{R} < 1$) observed in the double ratio at both energies, and with any choice of reference sample and MC simulation. This shown in Fig.1(c), corresponding to the plot in Fig.1(a) with a zoomed ordinate axis. The fit with $\Omega(Qr) = e^{-Qr}$ shows a deviation from the data trend around the minimum ($Q \sim 0.7$ GeV) and for $Q \geq 1.8$ GeV. The other curve in Fig.1(c) was generated by a parameterization of the correlation function proposed in [8] for describing point-like interactions, such as in e^+e^- collisions (such a structure was observed in e^+e^- collisions at LEP [9]), i.e.,

$$R^*(Q) = \mathscr{R}(Qr) = C\left[1 + \lambda\left(\cos\left[(r_0 Q)^2 + \tan(\alpha\pi/4)(Qr_\alpha)^\alpha\right] e^{-(Qr_\alpha)^\alpha}\right)\right] \cdot (1 + \delta Q). \qquad (2)$$

This parameterization describes the time evolution of the source by means of a one-sided asymmetric Lévy distribution. The parameter r_0 is related to the proper time of the onset of particle emission, r_α is a scale parameter, and α corresponds to the Lévy index of stability. Fits obtained with Eq. (2) are of good quality, with $\chi^2/N_{\rm dof} = 215/192$ and $\chi^2/N_{\rm dof} = 213/192$ at 7 TeV and 0.9 TeV, respectively.

The dip structure was studied as a function of k_T, showing little sensitivity. The depth in this anticorrelation region was also investigated as a function of $N_{\rm ch}$, and is found to decrease

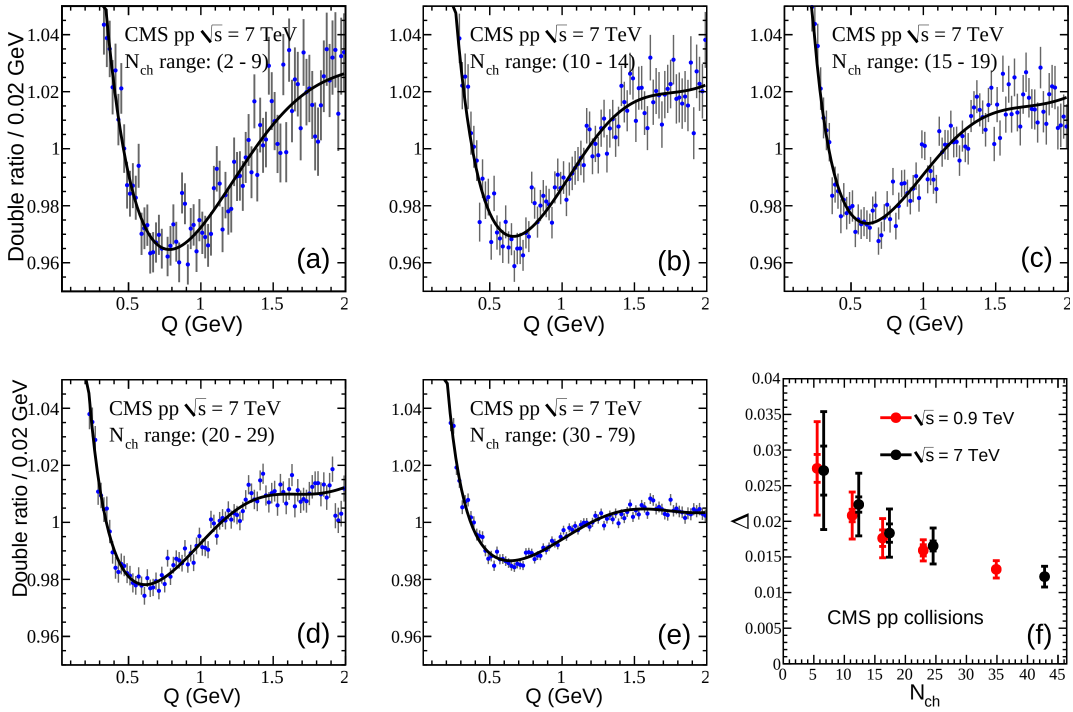

Figure 2: A decrease in the anticorrelation structure (dip) for increasing charged multiplicity is shown in parts (a) to (e). In (f), the dip's depth is shown in terms of the parameter $\Delta = C(1+\delta Q) - R^*(Q)$, at the minimum.

consistently with this variable as can be seen from the plots in parts Fig.2.(a)-(e). The depth of the dip was also quantified as the difference, Δ, between the baseline curve defined as $C \cdot (1+\delta Q)$ and the value of $\mathscr{R}(Q)$ defined by Eq.(2) as $R^*(Q)$, at its minimum. It is shown in Fig.2(f) as a function of N_{ch}, for both $\sqrt{s} = 0.9$ TeV and 7 TeV. This detailed observation is made possible by the large data samples studied, and constitutes the first evidence of this effect at the LHC [3, 4].

In summary, results of Bose–Einstein correlations measured using data collected with the CMS experiment in *pp* collisions at the LHC were shown here. The effective emission radius, r, is observed to increase with the event charged-particle multiplicity. The parameter r is nearly independent of the average transverse momentum of the pair of particles at the lowest multiplicity range, and decreases with k_{T} in events with large charged-particle multiplicities. For the first time in pp interactions, anticorrelations between same-sign charged particles are observed for Q values above the signal region, as previously reported with LEP data. The anticorrelation effects decrease with increasing charged-particle multiplicity in the event considered in this analysis.

References

References

[1] W. Kittel, E.A. De Wolf, “Soft Multihadron Dynamics” (World Scientific, 2005); G. Alexander, “Bose-ŰEinstein and Fermi-ŰDirac interferometry in particle physics”, Rep. Prog. Phys. 66 (2003) 481; R. M. Weiner, “Boson Interferometry in High-Energy Physics”, Phys. Rep. 327 (2000) 249.

[2] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 3 (2008) S08004.

[3] CMS Collaboration, “First Measurement of Bose–Einstein Correlations in proton-proton Collisions at $\sqrt{s} = 0.9$ and 2.36 TeV at the LHC”, Phys. Rev. Lett. 105 (2010) 032001 [arXiv:1005.3294]. *Phys. Rev. Lett.* **83** 4013.

[4] CMS Collaboration, “Measurement of Bose–Einstein correlations in pp collisions at $\sqrt{s} = 0.9$ and 7 TeV”, JHEP05 (2011) 029 [arXiv:1101.32518].

[5] M. Gyulassy, S.K. Kaufmann and L.W. Wilson, “Pion interferometry of nuclear col lisions. I. Theory”, Phys. Rev. C 20 (1979) 2267.

[6] E735 Collaboration, “Study of source size in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV using pion interferometry”, Phys. Rev. D48 (1993) 1931; STAR Collaboration, “Pion femtoscopy in p p collisions at $\sqrt{s} = 200$ GeV”, arXiv:1004.0925v2 (2010);

[7] ALICE Collaboration, “Two-pion Bose–Einstein correlations in pp collisions at $\sqrt{s} = 900$ GeV”, Phys. Rev. D82 (2010) 052001.

[8] T. Csörgő and J. Zimányi, “Pion Interferometry for Strongly Correlated Space-Time and Momentum Space”, Nucl. Phys. A 517 (1990) 588.

[9] L3 Collaboration, “Test of the τ-model of Bose–Einstein correlations and reconstruction of the source function in hadronic Z-boson decay at LEP”, Eur. Phys. J. C (2011) 71.

PoS(WPCF2011)015