

Recent results on femtoscopic correlations with the CMS experiment

Cesar A. Bernardes^{a,b,*} (on behalf of the CMS Collaboration)

^a*Instituto de Física, Universidade Federal do Rio Grande do Sul (UFRGS),
Av. Bento Gonçalves 9500, Porto Alegre, Brasil*

^b*Instituto de Física Teórica, Universidade Estadual Paulista (UNESP),
R. Dr. Bento Teobaldo Ferraz 271, São Paulo, Brasil*

E-mail: cesar.augusto.bernardes@cern.ch

The study of femtoscopic correlations in high-energy collisions is a powerful tool to investigate the space-time structure of the particle emitting region formed in such collisions, as well as to probe interactions that the involved particles may undergo after being emitted. An overview of the recent results from the CMS experiment at the LHC on the two-particle femtoscopic correlations measurements using charged particles and identified hadrons in pp and PbPb collisions is presented. In general, the femtoscopic parameters are obtained assuming a Gaussian or an exponential shape to describe the emitting source distribution. In some cases, however, the generalized Gaussian, i.e., the symmetric alpha-stable Lévy distribution, is favored to describe the source. Some of the measurements allow to extract the parameters of the strong interaction felt by hadrons using their femtoscopic correlations. The studies are performed in a wide range of the pair average transverse momentum (or average transverse mass) and charged particle multiplicities. In addition, prospects for future physics results using the CMS experiment are also discussed.

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*Speaker

1. Introduction

Femtoscopic correlations are a powerful tool to investigate the spatiotemporal scale of the particle emitting source and the final state interactions (e.g. Coulomb and strong interactions) among the hadrons produced in hadronic and heavy-ion collisions [1]. In this proceedings, results on the two-particle femtoscopic correlations are presented using proton-proton (pp) and lead-lead (PbPb) collision data from the CMS experiment at the LHC [2].

Femtoscopic correlations using unidentified charged particles are measured in pp collisions with a center of mass energy of 13 TeV, analyzing events going up to about 250 reconstructed charged hadrons [3]. These measurements explore very high particle multiplicity events, where the phenomena of collectivity (similar to the ones from heavy-ion collisions) were observed [4]. The studies were performed using the variable: $q_{\text{inv}}^2 = -q^\mu q_\mu = -(k_1 - k_2)^2$, where k_i refers to the four-momentum of each particle of the pair. The correlation function, also known as single ratio, is extracted by dividing the q_{inv} distribution from same-sign particle pairs taken from same event, with a q_{inv} distribution using pairs from mixed events. By fitting the correlation function¹ assuming a particle emitting source shape (in the case an exponential function), the following parameters are measured: the correlation strength (λ) and the source radius in one dimension (also called the length of homogeneity, here denoted as R_{inv} , or simply R). In order to study dynamical behavior of such parameters, they are measured as functions of the event multiplicity (N_{tracks}) as well as average pair momentum projection in transverse plane, $k_T = \frac{1}{2}|\vec{p}_{T,1} + \vec{p}_{T,2}|$, and mass, $m_T = \sqrt{m_\pi^2 + k_T^2}$, where all the hadrons are assumed to be pions.

In heavy-ion collisions, the Gaussian and exponential functions are usually considered for fitting the correlation function. A generalized form, called Lévy alpha-stable distribution, has also been considered [5]. This function provided a precise description of the correlation function of the data from the BNL RHIC facility in gold-gold collisions at 200 GeV [6], being characterized by an additional parameter called Lévy exponent (α). The results presented in this proceedings verify the applicability of the Lévy function at the LHC energies in PbPb collisions, and also investigate if the parameter R_{inv} behaves as a particle emitting source size as a function of particle multiplicity (or the number of participants nucleons in the collision, N_{part}), k_T or m_T . Usually the behavior of such parameters as a function of N_{part} , k_T or m_T can be described by hydrodynamic models assuming a Gaussian shape for the particle emitting source [7].

Femtoscopic correlations using K_s^0 mesons and Λ baryons (called V^0 particles) have the advantage to be not affected by Coulomb final state interactions. In addition to the quantum statistics phenomena with identical particle correlations, the V^0 particle correlations are sensitive to strong final state effects, which are very important for the understanding of the strong interaction in the non-perturbative scenario. Such measurements have also applicability in the study of the composition of the core of neutron stars [8]. The results presented in this proceedings consider the Lednicky–Lyuboshits (LL) model [9] to described the strong interaction hadron-hadron scattering parameters.

¹Is important to mention that, in general, methods to subtract non-femtoscopic contributions to the correlation function (mainly from mini-jets, resonances, momentum conservation, flow, etc...) should be applied.

2. Results

Figure 1 shows the measurements of R_{inv} as a function of m_T and $N_{\text{part}}^{1/3}$ for PbPb and of k_T and $(dN_{\text{tracks}}/d\eta)^{1/3}$ for pp collisions. In PbPb, the source scale follows a very similar trend as observed when using the Gaussian shape [7], i.e., decreases as a function of m_T and increases linearly as a function of $N_{\text{part}}^{1/3}$. The measurements as a function of m_T are performed for different centrality classes, which is a measure of the overlap of the two Pb nuclei. In pp collisions, similar trends as compared to PbPb are observed, except for that at higher values of $(dN_{\text{tracks}}/d\eta)^{1/3}$, where the data could also be consistent with a saturation in the magnitude of R_{inv} , a feature to be understood. Notice that a very similar trend was also observed in the ATLAS measurements [10].

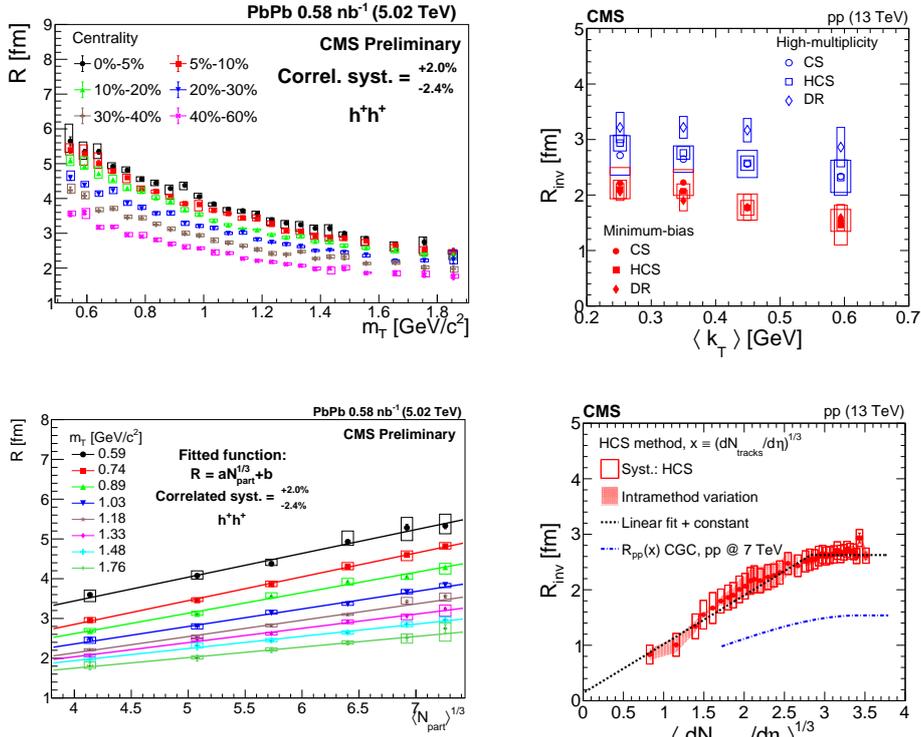


Figure 1: (Upper) R_{inv} as a function of m_T and k_T . (Lower) R_{inv} as a function of $N_{\text{part}}^{1/3}$ and $(dN_{\text{tracks}}/d\eta)^{1/3}$. Left plots are from PbPb collisions, while right plots are from pp collisions [3, 7].

In hydrodynamic calculations [11, 12], considering a Gaussian source shape, it is possible to find a relation between $1/R_{\text{inv}}^2$ and m_T . A linear relation is expected, with the slope connected to radial flow (larger slope corresponds to larger radial flow), in addition, the extrapolation to $m_T \rightarrow 0$ is related to the source size at the kinetic freeze-out, called geometrical size. Figure 2 shows these relations for PbPb and pp collisions. For PbPb, using Lévy function to parameterize the emission source, the behavior on the slope is observed, but the extrapolation of $m_T \rightarrow 0$ gives a negative value, which is not trivial to interpret [7]. Figure 3 shows that the α parameter has almost no dependence as a function of m_T variable and a slight dependence on N_{part} , getting closer to 2 (Gaussian function) for higher values of N_{part} . A similar behavior for pairs with positive and negative electric charge is seen. As observe in Fig. 4, the correlation strength decreases with m_T

and k_T for PbPb and pp collisions, respectively. A possible explanation for this trend is attributed to the lack of particle identification (see Ref. [7] for discussions).

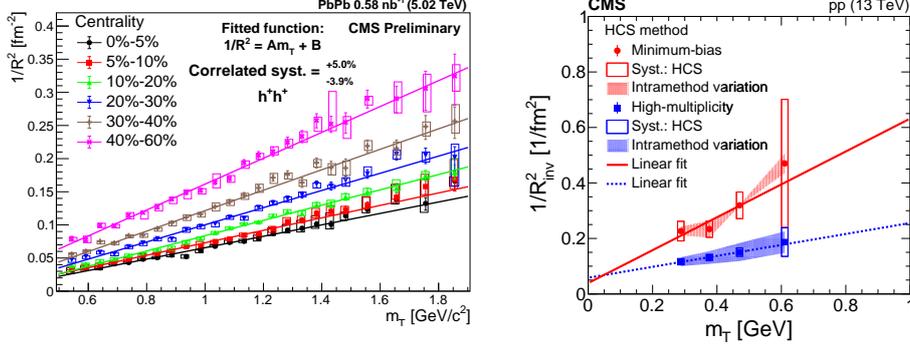


Figure 2: $1/R^2_{\text{inv}}$ as a function of m_T for PbPb collisions (left) and pp collisions (right) [3, 7].

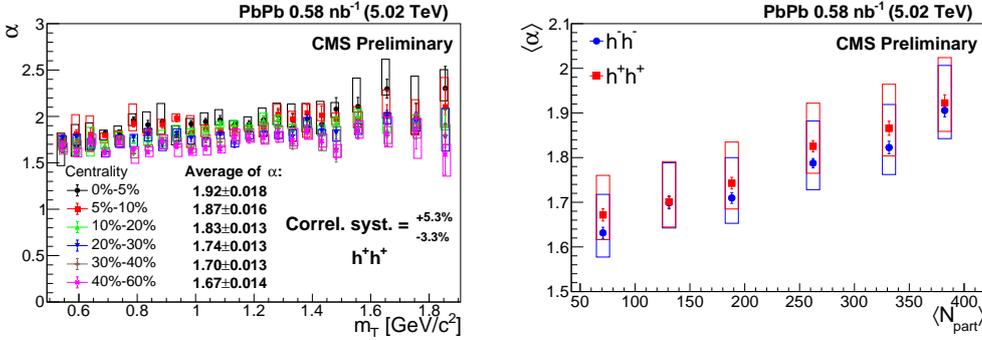


Figure 3: Lévy α parameter as a function of m_T and its average value as a function of N_{part} [7].

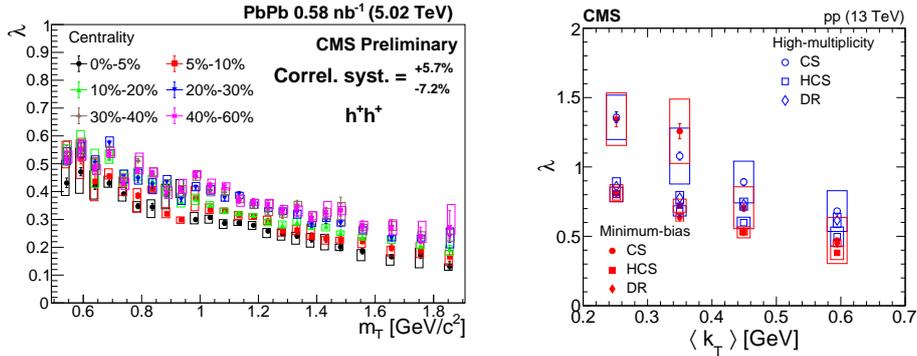


Figure 4: Correlation strength parameter as a function of m_T and k_T for PbPb and pp collisions, respectively [3, 7].

The K_s^0 mesons and Λ baryons are reconstructed in the $\pi^+\pi^-$ and $p\pi^-$ channels, respectively. For the $K_s^0K_s^0$ correlations, the strong interaction LL model parameters are fixed by using inputs from low energy experiments [8]. Figure 5 shows R_{inv} and λ as functions of collision centrality. The R_{inv} and λ parameters decrease with centrality, similarly as observed in many measurements with unidentified and other identified particles. The effect of the strong interaction parameterization

in the values of R_{inv} and λ was also tested, showing a considerable difference between both cases. The Λ baryon correlations are used to measured the scattering parameters of the LL model, such as the real part of the scattering length ($\Re f_0$) and effective range (d_0) [8]. The cases with $\Re f_0 < 0$ are interpreted as an anticorrelation (depletion below unit or a repulsive interaction) and the scenarios with $\Re f_0 > 0$ are interpreted as a correlation above unit (attractive interaction). Figure 6 shows these parameters for the $\Lambda \Lambda \oplus \bar{\Lambda} \bar{\Lambda}$ and $\Lambda K_S^0 \oplus \bar{\Lambda} K_S^0$ correlations, indicating an attractive interaction for $\Lambda \Lambda \oplus \bar{\Lambda} \bar{\Lambda}$ and a repulsive interaction for $\Lambda K_S^0 \oplus \bar{\Lambda} K_S^0$. The result for $\Lambda K_S^0 \oplus \bar{\Lambda} K_S^0$ differs from those reported by the ALICE collaboration [13] for PbPb collisions at 2.76 TeV.

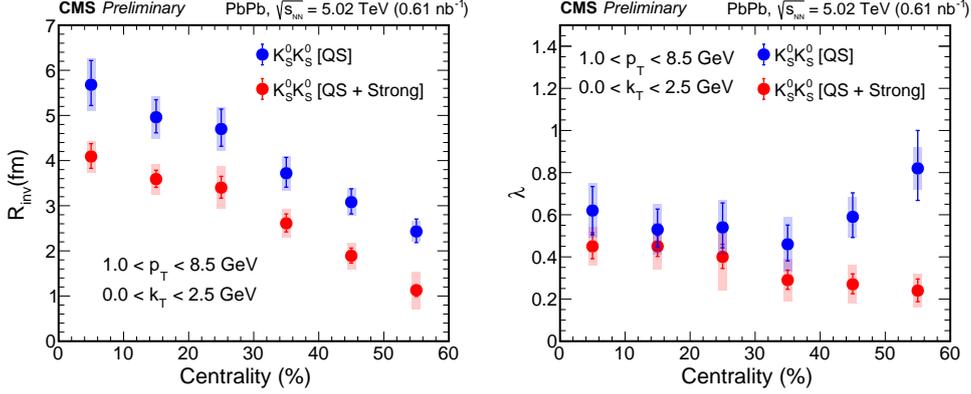


Figure 5: R_{inv} and λ parameters from $K_S^0 K_S^0$ correlations as functions of collision centrality [8].

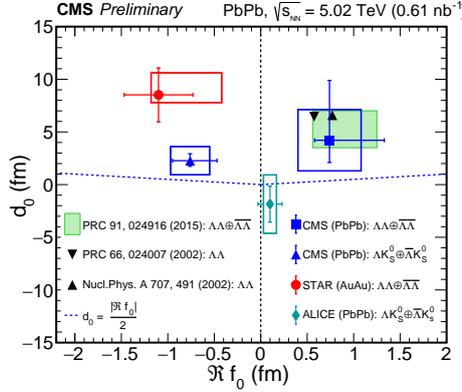


Figure 6: Scattering parameters from the LL model. CMS measurements for $\Lambda \Lambda \oplus \bar{\Lambda} \bar{\Lambda}$ and $\Lambda K_S^0 \oplus \bar{\Lambda} K_S^0$ are compared with STAR, ALICE and NAGARA event [8].

3. Conclusions

In summary, femtoscopic correlations for charged hadrons, K_S^0 mesons, and Λ baryons are measured in proton-proton and lead-lead collisions with the CMS experiment. The measured particle emitting source parameters in general show similar behavior between the two colliding systems. For charged hadrons, in PbPb collisions, a Lévy alpha-stable distribution is used to describe the correlation function, showing a very good description of the data and fitting parameters

with dynamical behavior compatible with a particle emitting source size. Measurements using the K_s^0 mesons and Λ baryons suggest an attractive and a repulsive interaction for $\Lambda \Lambda \oplus \bar{\Lambda} \bar{\Lambda}$ and $\Lambda K_s^0 \oplus \bar{\Lambda} \bar{K}_s^0$, respectively.

Acknowledgments

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