Proposal for Two-Particle Correlation Analyses with BELLE Data

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(Dated: March 16, 2017)

Abstract

This paper proposes measurements of two-particle angular correlations of charged hadrons produced in e^+e^- collisions, as a function of charged hadron multiplicity, which will enable a direct comparison between e^+e^-, pp, pA and AA collisions for the first time. Preliminary results from BELLE open data are also presented.

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I. INTRODUCTION

This paper proposes measurements of two-particle angular correlations of charged hadrons produced in e^+e^- collisions, as a function of charged hadron multiplicity. Two-particle correlations in high-energy collisions provide valuable information for characterizing Quantum Chromodynamics and have been studied previously for a broad range of collision energies in proton-proton (pp) [2], proton-nucleus (pA) [1], and nucleus-nucleus (AA) collisions. Such measurements can elucidate the underlying mechanism of particle production and reveal possible collective effects resulting from the high particle densities accessible in these collisions.

Studies of two-particle angular correlations are typically performed using two-dimensional $\Delta\eta - \Delta\phi$ correlation functions, where $\Delta\phi$ is the difference in the azimuthal angle ϕ between the two particles and $\Delta\eta$ is the difference in pseudorapidity $\eta = -\ln(\tan(\theta/2))$. The polar angle θ is defined relative to the counterclockwise beam direction.

Of particular interest in studies of collective effects is the long-range (large $|\Delta\eta|$) structure of the two-particle correlation functions. In this region, the function is less susceptible to known sources of correlations such as resonance decays and fragmentation function of energetic jets. Measurements in high-energy AA collisions have shown significant modification of the long-range structure compared with minimum-bias pp collisions, over a very wide range of collision energies. This long-range correlations are commonly interpreted as a consequence of the hydrodynamical flow of the produced strongly interacting medium and usually characterized by the Fourier components of the azimuthal particle distributions. The extraction of the second and third Fourier components, usually referred to as elliptic and triangular flow, is of great interest because it is closely related to initial collision geometry and its fluctuation. Those measurements allows the extraction of the fundamental transport properties of the medium using hydrodynamic models.

Recently, measurements in pp collisions and pPb collisions have revealed the emergence of long-range, near-side ($\Delta\phi \sim 0$) correlations in the selection of collisions with very high number of final state particles. This "ridge-like" correlation has inspired a large variety of theoretical models. Moreover, it was found that the elliptic flow signal exists at the lowest nucleon-nucleon center-of-mass energy of 7.7 GeV in AA collisions at the Relativistic Heavy Ion Collider.

Studies of two-particle correlation in high multiplicity e^+e^- will enable a direct comparison between different collision systems for the first time. Moreover, the total energy involved in the e^+e^- collisions are very well understood such that one could start with a well-defined initial condition. The observation of ridge in e^+e^- collisions (or the non-observation) will bring significant impact to the field of relativistic heavy ion collisions, either change completely the interpretation of the ridge in pp, pA and AA collisions, or serve as an important reference for the final state effect observed in high multiplicity hadron-hadron scatterings. The high performance BELLE detector is ideally suited for the proposed measurement and preliminary results from the BELLE B-lab open data is presented in this proposal.

II. TWO-PARTICLE CORRELATION FUNCTION

In this analysis with BELLE open data, identified protons, pions and kaons with transverse momentum between 0.1 and 4.0 GeV/c are selected for the correlation function analysis. High multiplicity events are sampled using the total number of selected proton, pions and kaons (hadron multiplicity N) in each event. The first step in extracting the correlation function was to divide the sample into bins in the hadron multiplicity. For each hadron multiplicity class, "trigger" particles are defined as charged particles originating from primary vertex in the selected transverse momentum range (0.1 and 4.0 GeV/c). The number of trigger particles in the event is denoted by N_{trig}. Particle pairs are then formed by associating every trigger particle with the remaining charged primary particles in the same p_{T} interval as the trigger particle. The per-trigger-particle associated yield is defined as:

$$\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2\mathrm{N}^{\mathrm{pair}}}{d\Delta\eta\mathrm{d}\Delta\phi} = B(0,0)\times\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)} \tag{1}$$

where $\Delta\eta$ and $\Delta\phi$ are the differences in η and ϕ of the pair. The signal distribution, $S(\Delta\eta,\Delta\phi)$, is the per-trigger-particle yield of particle pairs in the same event:

$$S(\Delta\eta,\Delta\phi) = \frac{1}{N_{trig}}\frac{\mathrm{d}^2\mathrm{N}^{\mathrm{same}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta\phi} \tag{2}$$

The mixed-event background distribution, used to account for random combinatorial background, is defined as

$$B(\Delta\eta,\Delta\phi) = \frac{1}{N_{trig}}\frac{\mathrm{d}^2\mathrm{N}^{\mathrm{mix}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta\phi} \tag{3}$$

and is constructing by pairing the trigger particles from two random events in the same hadron multiplicity interval. The simbol N^{mix} denotes the number of pairs taken from the mixed event, while $B(0,0)$ represents the mixed-event associated yield for both particles of the pair going in the same direction and thus having full pair acceptance. Therefore, the ratio $B(0,0)/B(\Delta\eta,\Delta\phi)$ represents the pair-acceptance correction factor used to derive the corrected per-trigger-particle associated yield distribution. The signal and background distributions are first calculated for each event, and then averaged over all the events within the track multiplicity class.

III. PRELIMINARY RESULTS FROM BELLE OPEN DATA

Figure 1 shows the multiplicity distribution of identified particles (pions, kaons and proton) obtained after applying the selection on the particle transverse momentum ($0.1 < p_{\mathrm{T}} < 4.0$ GeV/c). The dominant contribution to the total multiplicity is coming as expected from pions. In Fig. 2, the charged hadron multiplicity distribution N is shown: the largest multiplicity observed in these events is about 70.

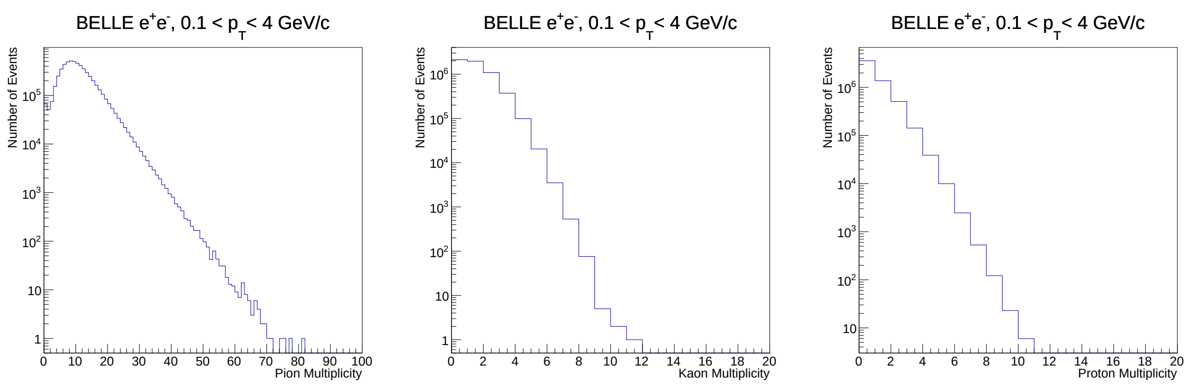

FIG. 1. Multiplicity distributions of pions (left), kaons (middle), protons (right) for particles in the range $0.1 < p_{\mathrm{T}} < 4.0$ GeV/c in e^+e^- collisions.

In this proposal we present the first study of two particle correlations with e^+e^- with the BELLE experiment using open data. In Fig. 3 we compare the two-particle correlation functions for events with low (N>20) and high multiplicity(N> 40). In the low-multiplicity result, the dominant features are the correlation peak near $(\Delta\eta,\Delta\phi) = (0,0)$ for pairs of particles originating from the same jet and the elongated structure at $\Delta\phi \sim \pi$ for pairs of

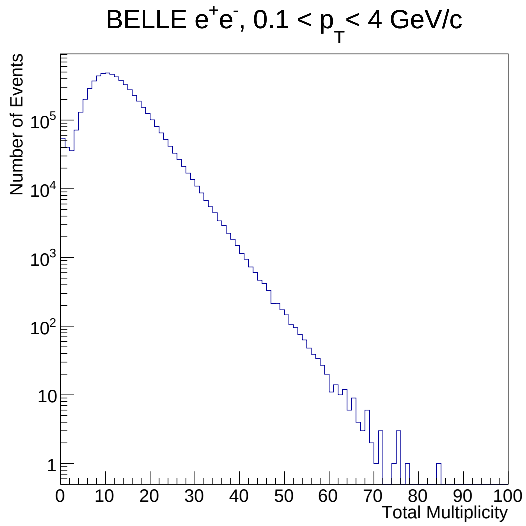

FIG. 2. Multiplicity distribution of charged hadrons (protons, kaons and pions) for particles in the range $0.1 < p_{\mathrm{T}} < 4.0$ GeV/c in e^+e^- collisions.

particles from back-to-back jets. To better illustrate the full correlation structure, the jet peal has been truncated. Moving from low-multiplicity to high-multiplicity selection, the same-side jet peak and back-to-back correlation structures can be observed. However, in addition, a hint of "ridge"-like structure is visible at $\Delta\phi$ ∼0. This ridge has characteristics which are similar to the structures observed in high multiplicity pp and pPb collisions at $\sqrt{s_{NN}}$ and in AA collisions over a wide range of energies.

To check if a long-range ridge structure exists, one-dimensional distributions in $\Delta\phi$ are obtained by integrating over different $|\Delta\eta|$ interval, 0< $\Delta\eta$ <1 (left) and 2< $\Delta\eta$ <3 (right). In the left side plot, we can clearly identify the near side peak at $\Delta\phi$ =0 and the back-to-back peak at $\Delta\phi = \pi$. At large pseudorapidities, a hint of signal at $\Delta\phi = 0$ seems to confirm the observation of a long-range correlation structure. This preliminary observation motivates a detailed study with the highest statistics data taken by the BELLE collaboration.

IV. SUMMARY

The BELLE open data has been used to measure angular correlations between two charged particles. A hint of long-range ridge-like structure at the near-side ($\Delta\phi \sim 0$) was seen in the BELLE data. The observation of long-range near-side ridge like correlation (or

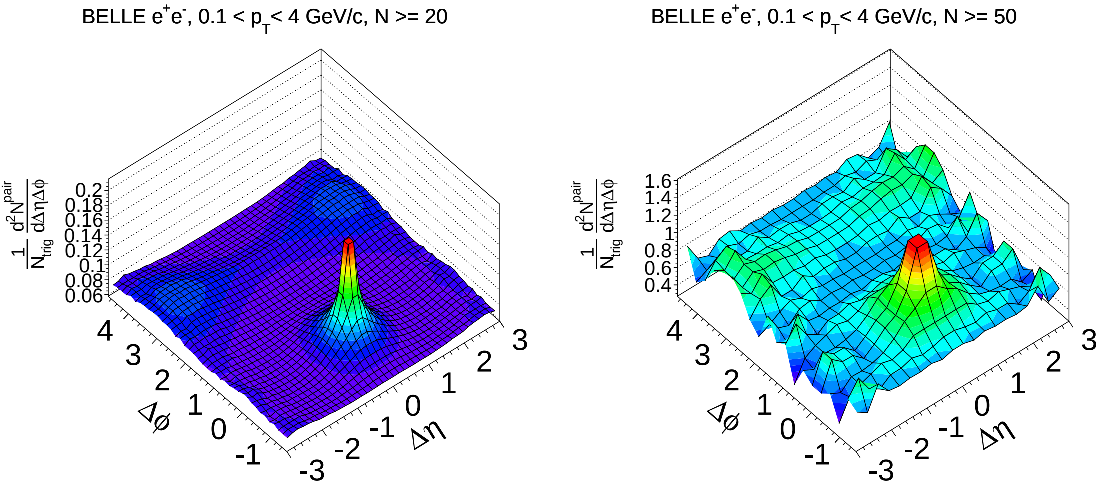

FIG. 3. Two-particle correlation functions versus $\Delta\eta$ and $\Delta\phi$ in e^+e^- collisions for events with particle multiplicity > 20 (left) and > 50 (right).

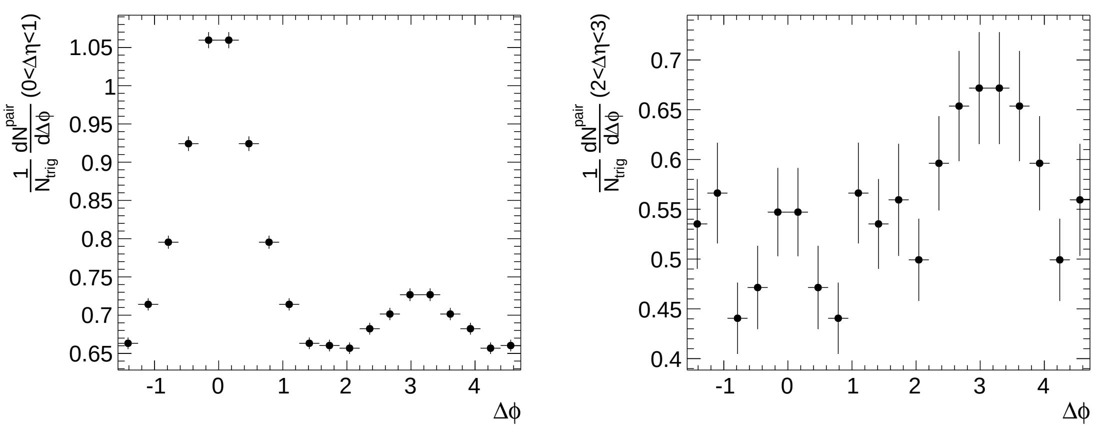

FIG. 4. Two-particle correlation functions as a function of $\Delta\phi$ in e^+e^- in the pseudorapidity ranges 0< $\Delta\eta$ <1 (left) and 2< $\Delta\eta$ <3 (right).

the non-observation) will bring significant impact to the interpretation of the pp and AA data.

[1] Serguei Chatrchyan et al. Observation of long-range near-side angular correlations in proton-lead collisions at the LHC. *Phys. Lett.*, B718:795–814, 2013.

[2] Vardan Khachatryan et al. Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions at the LHC. *JHEP*, 09:091, 2010.