Proposal for Two-Particle Correlation Analyses with ALEPH Data

Anthony Badea, Austin Baty, Gian Michele Innocenti,
Yen-Jie Lee, Bibek Pandit, Michael Peters, and Jesse Thaler
Massachusetts Institute of Technology

Paoti Chang and Tzu-An Sheng
National Taiwan University

Marcello Maggi
Universita degli Studi di Bari

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Abstract

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), proton-nucleus (pA), and nucleus-nucleus (AA) collisions. In AA collisions, a significant long-range angular correlation between particles was observed. The common interpretation of the results based on the hydrodynamics calculations was that a thermalized system was created in the AA collisions. Recently, similar correlation signals were observed in high particle multiplicity pp and pA collisions. The physical origin of the phenomenon is not yet fully understood. Due to the complexity of the hadron-hadron collisions, possible initial state correlations of the partons, such as those arise from color-glass condensate, could complicate the interpretation of the pp and pA data. Studies of high multiplicity e^+e^- collision, where the initial kinematics of the collisions are well-controlled, could bring significant insights about the observed phenomenon. This paper proposes measurements of two-particle angular correlations of charged hadrons produced in e^+e^- collisions, as a function of charged hadron multiplicity with the ALEPH detector. These measurements 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.

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 with the Belle detector. 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) [1], proton-nucleus (pA) [2–4], and nucleus-nucleus (AA) [5, 6] 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 hadron 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 other 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 [7–10]. The long-range correlations are commonly interpreted as a consequence of the hydrodynamical flow of the produced strongly interacting medium [11] 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 [12]. Those measurements allow the extraction of the fundamental transport properties of the medium using hydrodynamic models.

Recently, measurements in pp [1] and pPb collisions [2–4] 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 [13, 14]. The physical origin of the phenomenon is not yet fully understood. Moreover, it was found that the elliptic flow signal exists even at the lowest nucleon-nucleon center-of-mass energy of 7.7 GeV in AA collisions at the Relativistic Heavy

Ion Collider [15].

Due to the complexity of the hadron-hadron collisions, possible initial state correlations of the partons, such as those arise from color-glass condensate [16, 17], could complicate the interpretation of the pp and pA data. Studies of high multiplicity e^+e^- collision, where the initial kinematics of the collisions are well-controlled, could bring significant insights about the observed phenomenon. These measurements will also enable a direct comparison between different collision systems for the first time. The studies of ridge signal in e^+e^- collisions 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 if a significant signal is observed, or serve as an important reference for the final state effect observed in high multiplicity hadron-hadron scatterings if no long-range correlation signal was detected.

The Belle detector is ideally suited for the proposed measurements due to its high performance and large acceptance. Preliminary results from the Belle B-lab open data with the analysis method used in pA and AA collisions is presented in this proposal. Potential improvements of the analysis procedure could be implemented for the studies with full Belle hadronic data.

II. DATA SAMPLE

Document the ALEPH data used in this analysis

III. DATA QUALITY CHECKS

IV. ANALYSIS

V. THRUST AXIS

VI. REPRODUCING QCD PAPER PLOT

VII. TWO-PARTICLE CORRELATION FUNCTION

In this analysis with ALEPH open data, charged particles with transverse momentum between 0.1 and 4.0 GeV/c are selected for the correlation function analysis. High multiplicity

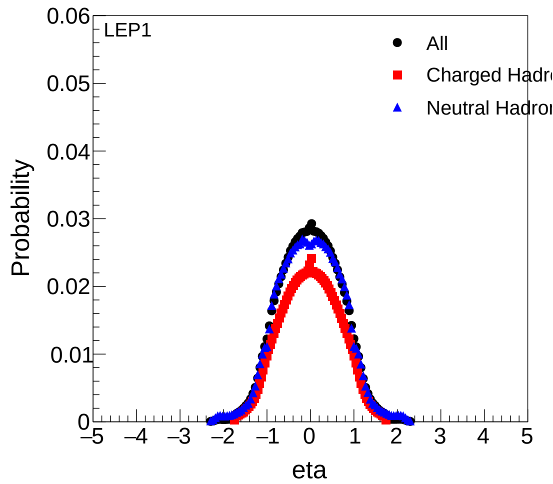

FIG. 1. LEP1 Eta Spectra

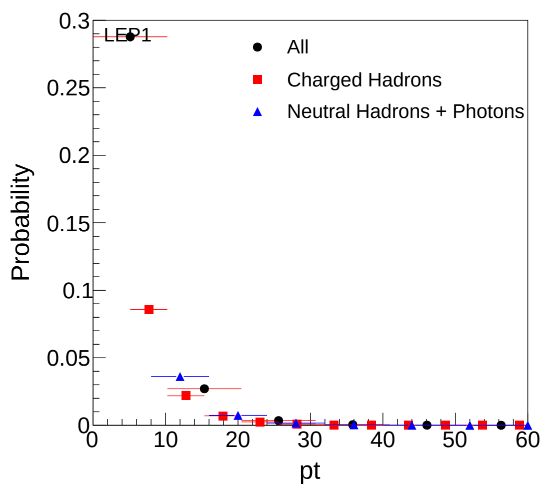

FIG. 2. LEP1 PT spectra

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 hadrons in the selected transverse momentum range (0.1 and 4.0 GeV/c). Particle pairs are then formed by associating every trigger particle with the remaining charged hadrons in the same p_{T} interval as the trigger particle. The

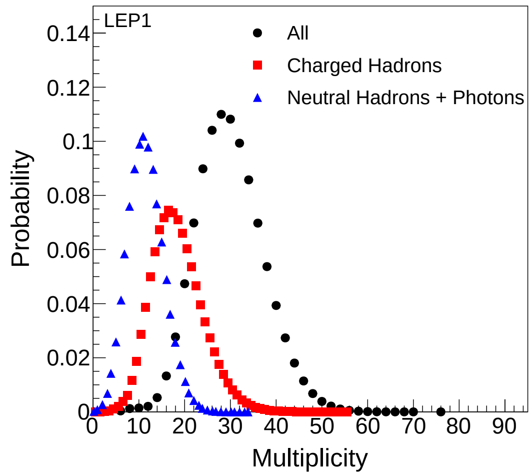

FIG. 3. LEP1 Multiplicity Distribution

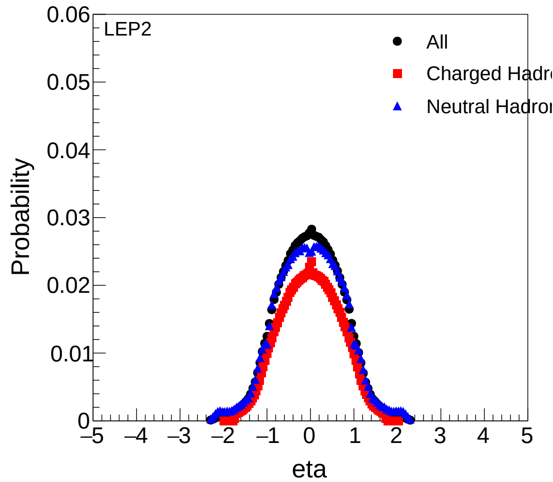

FIG. 4. LEP2 Eta Spectra

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 N_{trig} is the number of trigger particles in the event, $\Delta\eta$ 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

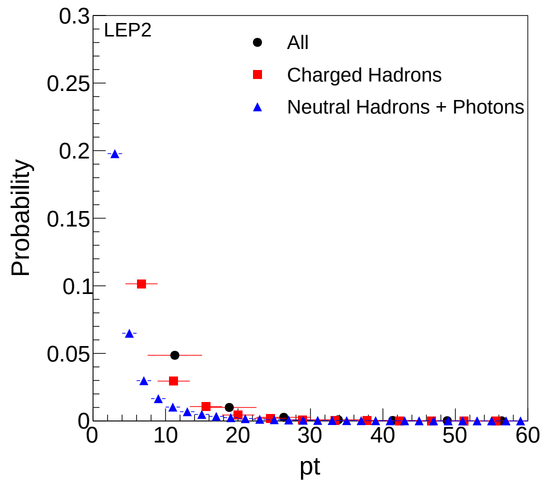

FIG. 5. LEP2 PT spectra

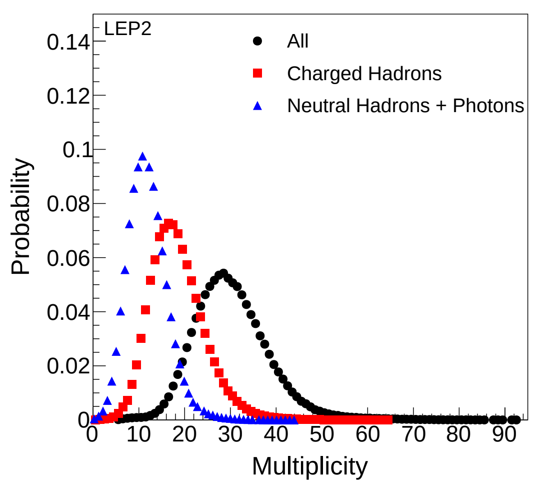

FIG. 6. LEP2 Multiplicity Distribution

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

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

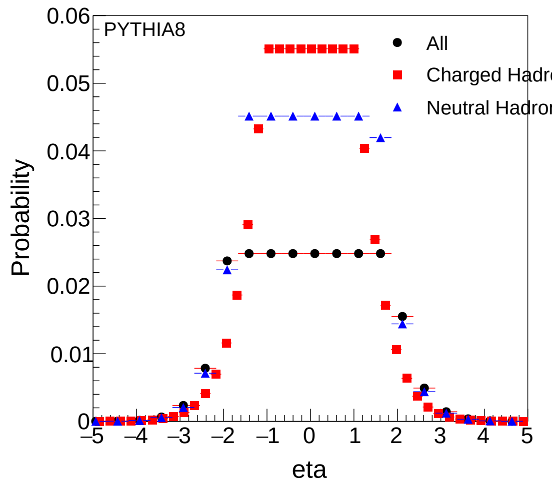

FIG. 7. PYTHIA8 Eta Spectra

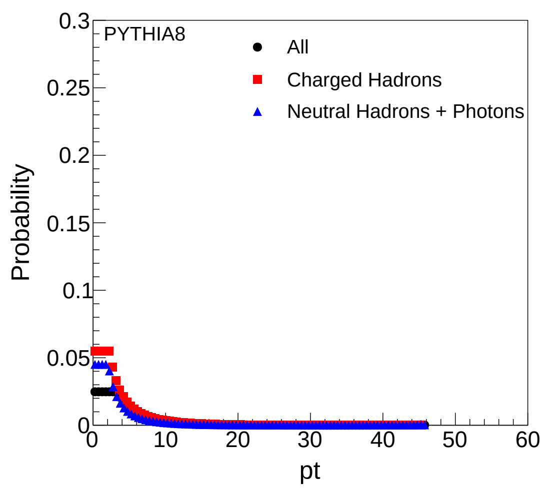

FIG. 8. PYTHIA8 PT spectra

and is constructing by pairing the trigger particles from two random events in the same hadron multiplicity interval. The symbol 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

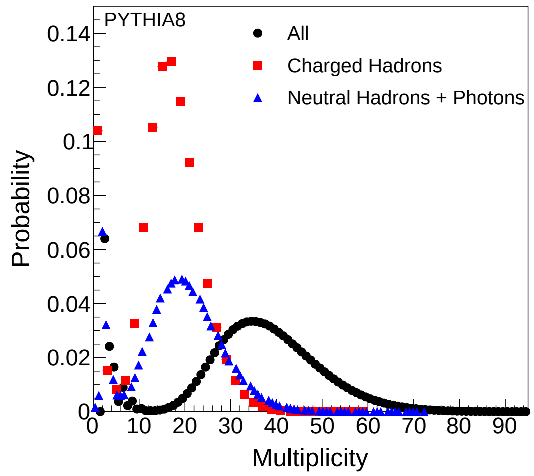

FIG. 9. PYTHIA8 Multiplicity Distribution

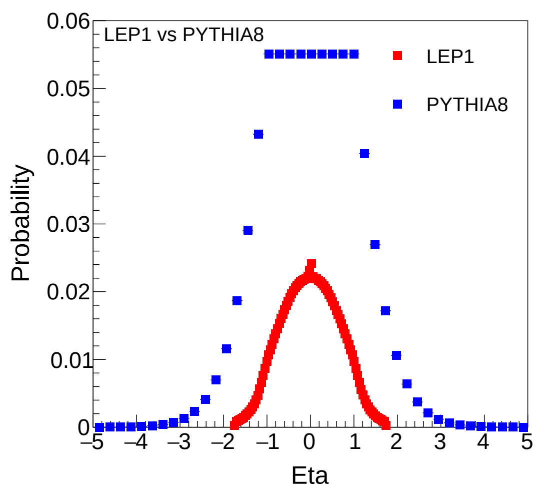

FIG. 10. LEP1 vs PYTHIA8 Eta Spectra of charged hadrons

distributions are first calculated for each event and then averaged over all the events within the track multiplicity class.

In the full data analysis, a matching between particles and the primary vertex should be performed so that the studies are done with primary hadrons from a single primary vertex. This matching requirement is not yet included in this preliminary analysis due to the limited information in the Belle open data.

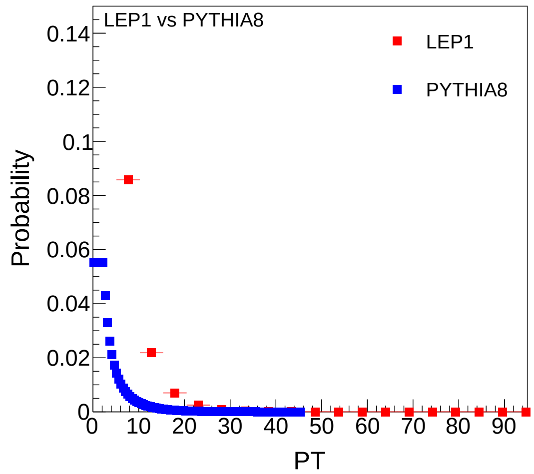

FIG. 11. LEP1 vs PYTHIA8 PT spectra of charged hadrons

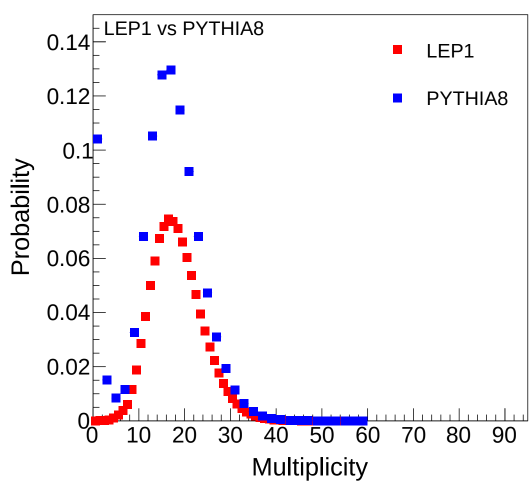

FIG. 12. LEP1 vs PYTHIA8 Multiplicity Distribution of charged hadrons

VIII. SYSTEMATICAL UNCERTAINTIES

IX. PRELIMINARY RESULTS FROM BELLE OPEN DATA

A. Charged hadron multiplicity distributions

Figure 1 shows the multiplicity distribution of identified hadrons (pions, kaons and protons) 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 event multiplicity is coming from pions as expected. In Fig. 2, the charged hadron multiplicity distribution N is shown. The multiplicity distribution is smooth and the largest raw particle multiplicity observed in these events is about 70 before corrections for tracking efficiency, misidentification and multiple reconstruction rates, which is large given the relatively low center-of-mass energy of the collisions. Detailed studies of primary vertex-track matching and track quality as well as possible pile-up event rejection are needed for the full Belle data analysis and those effects could lower the significance of the possible correlation signals.

FIG. 13. Uncorrected 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.

FIG. 14. 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.

B. Two-particle correlation functions

In Fig. 3, the two-particle correlation functions from low (N>20) and high multiplicity (N> 50) events are presented. In low-multiplicity events, the dominant features of the correlation function are the jet 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 particles from back-to-back jets. The same-side jet peak and back-to-back correlation structures are also observed in high multiplicity events. In addition, a hint of "ridge"-like structure is visible at $\Delta\phi \sim 0$ in the right panel of Fig. 3.

To separate and inspect the long-range and short-range structure, one-dimensional distributions in $\Delta\phi$ are obtained by integrating over two $|\Delta\eta|$ intervals: $0 < |\Delta\eta| < 1$ and $2 < |\Delta\eta| < 3$. At small $\Delta\eta$, a near-side peak at $\Delta\phi = 0$ and the contribution from the back-to-back jet at $\Delta\phi = \pi$ is observed in the left panel of Fig 4. At large $\Delta\eta$, a near-side peak at $\Delta\phi = 0$ is shown in the right panel of Fig 4, similar to the structures observed in high multiplicity pp, pA and AA collisions over a wide range of energies. However, the significance of this signal is limited by the available statistics in the Belle open data. This motivates a detailed study with the high statistics hadronic data taken by the Belle collaboration.

FIG. 15. 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. 16. 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) for events with particle multiplicity > 50.

X. SUMMARY

The Belle open data has been used to perform measurements of two-particle angular correlation functions for the first time. A hint of long-range ($|\Delta\eta| > 2$) ridge-like structure at the near-side ($\Delta\phi \sim 0$) was shown in the Belle data. However, the limited statistics precludes drawing firm conclusions and we propose to perform those measurements with the unique high statistics hadronic data recorded by the Belle detector.

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