Understanding long-range near-side ridge correlations in p-p collisions using rope hadronization at energies available at the CERN Large Hadron Collider

Outline:
- Introduction
- Motivation
- Correlation Function
- Analysis Details
- Results

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Introduction

Two particle azimuthal correlation function is a robust tool to explore various physics phenomena of particle production in proton-proton and heavy ion collisions.

\[ C(\Delta \eta, \Delta \phi) = N \frac{S(\Delta \eta, \Delta \phi)}{B(\Delta \eta, \Delta \phi)} \]

- \( \Delta \eta = \eta_1 - \eta_2 = \) Relative pseudorapidity
- \( \Delta \phi = \phi_1 - \phi_2 = \) Relative azimuthal angle

Particle pairs from same event
Particle pairs from different events
Motivation (I)

Angular correlations originate from various phenomena

- “Away-side” ($\Delta \phi \sim \pi$) jet correlations: Correlation of particles between back-to-back jets
- Bose-Einstein correlations: ($\Delta \phi, \Delta \eta \sim (0, 0)$)
- Momentum conservation: $\sim -\cos(\Delta \phi)$
- “Near-side” ($\Delta \phi \sim 0$) jet peak: Correlation of particles within a single jet
- Resonances, string fragmentation

Ref: L. K. Graczykowski, and M. A. Janik, Nucl. Phys. A. 926, 205-212, (2014) https://doi.org/10.1016/j.nuclphysa.2014.03.004
Motivation (II) : p-Pb and Pb-Pb collisions

Hydrodynamic collective flow of a strongly interacting and expanding medium produced in heavy ion collision is responsible for these long-range correlations

[a]: S. Chatrchyan et al. (CMS Collaboration), J. High Energy Phys. 07 (2011) 076
[b]: S. Chatrchyan et al. (CMS Collaboration), Phys. Lett. B 718, 795 (2013).
Motivation (III) : p-p collisions

No ridge effect for low multiplicity events

First observation of ridge effect in high multiplicity p-p events

Evidence of collectivity in small systems produced in high-multiplicity p-p events

Ref: V. Khachatryan et al. (CMS Collaboration), Phys. Rev. Lett. 116, 172302 (2016).
Colour Reconnection in PYTHIA 8

Color Reconnection (CR) refers to the rearrangement of color fields before hadronisation

Various CR models:

- **MPI based scheme (CR 0):**
  Partons from lower $p_T$ fused with partons from higher $p_T$, total length of the colour strings calculated, configuration with minimum total string length chosen

- **QCD based scheme (CR 1):**
  - Incorporates QCD color rules, produces three color indices structure (“junctions”), leads to an enhancement of baryons, based on string minimization,

- **Gluon move scheme (CR 2):**
  Gluons considered for reconnections, configuration with minimum total string length chosen

Ref: T. Sjostrand et al, Comput. Phys. Commun. 191, 159 (2015).
Rope hadronization in PYTHIA 8

- Colour strings overlap with each other in high multiplicity events, form a color rope
- Greater energy density in the overlapping region
- Dynamic pressure gradient towards the transverse direction.
- Enhanced string tension produces heavier(s) quarks in string breaking

Ref: T. Sjostrand et al, Comput. Phys. Commun. 191, 159 (2015).
Two Particle Correlation: Construction

\[ S(\Delta \eta, \Delta \varphi) = \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{same}}}{d\Delta \eta d\Delta \varphi} \]

\[ B(\Delta \eta, \Delta \varphi) = \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{mix}}}{d\Delta \eta d\Delta \varphi} \]

\[ \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{pair}}}{d\Delta \eta d\Delta \varphi} = B(0, 0) \frac{S(\Delta \eta, \Delta \varphi)}{B(\Delta \eta, \Delta \varphi)} \]

Associated hadron yield per trigger
Analysis Details : PYTHIA 8 Simulation Studies

Event Generator : Pythia 8.2\textsuperscript{[a]}

System : p-p $\sqrt{s} = 7$ TeV and 13 TeV

Number of events : 100 Million

Particles Selected : charged hadrons

Kinematics cuts : $p_T > 0.4$ GeV/c,

$|\eta| < 2.4,$

$0 < \phi < 2\pi$

Effects to study : Color Reconnection and Rope Hadronization

\textsuperscript{[a]}: T. Sjostrand et al, Comput. Phys. Commun. 191, 159 (2015).
PYTHIA 8: Two Particle Correlations (I)

pp @ 7 TeV

No ridge like structure
(CR 2, RH off)

A small ridge like structure
(CR 2, RH on)

P. Chakraborty, and S. Dash, Phys. Rev. C 102, 055202 (2020)
PYTHIA 8: Two Particle Correlations (II)

pp @ 13 TeV

No ridge like structure
(CR 2, RH off)

A small ridge like structure
(CR 2, RH on)

P. Chakraborty, and S. Dash, Phys. Rev. C 102, 055202 (2020)
PYTHIA 8 : Two Particle Correlations (III)

1D $\Delta \phi$ correlation functions for the long-range region (pp @ 13 TeV):

$V. \text{Khachatryan et al. (CMS Collaboration), Phys. Rev. Lett. 116, 172302 (2016).}$

$P. \text{Chakraborty, and S. Dash, Phys. Rev. C 102, 055202 (2020)}$

$V. \text{Khachatryan et al. (CMS Collaboration), Phys. Rev. Lett. 116, 172302 (2016).}$
PYTHIA 8 : Two Particle Correlations (IV)

P. Chakraborty, and S. Dash, Phys. Rev. C 102, 055202 (2020)
Summary

- The microscopic models of color reconnection and rope hadronization describes the novel feature of near side ridge structure observed in pp collisions.

- The models mimic features of hydrodynamic expansion without assuming the formation of thermalized medium.

- However, the model parameter tunings need to be understood and improvised for other observables.
Thank you for your kind attention