Long range rapidity correlations in high energy nucleus collisions at RHIC and LHC

Heavy Ion Pub @ Ohsaka University
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Outline

• Overview of basic ridge property
• Ridge study via $\Delta \phi$ correlations with respect to Reaction Plane
• Triangular flow
• $\Delta \eta$ correlations with respect to trigger $\eta$
• Ridge in high multiplicity p+p events at LHC-CMS
• Summary
Long range rapidity correlations

- Long range rapidity correlations up to large rapidity = “Ridge”
- Seen in Au+Au, absent in d+Au collisions
- Superposition of jet and ridge at $\Delta \phi \sim 0$ & $\Delta \eta \sim 0$ in Au+Au collisions
Jet and Ridge yield $p_T$ spectra

- Jet spectrum is increasing with $p_T^{\text{trig}}$ as jet fragmentation.
- Ridge spectrum is softer and approximately independent of $p_T^{\text{trig}}$.
- Ridge is “bulk-like”.

*Ref.: Phys. Rev. C 80, 064912 (2009)*
Ridge shape gets clearer with $p_T$

Cu+Cu 200 GeV 0–10%, Chanaka De Silva, April APS Meeting 2010, STAR Preliminary

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Centrality evolution of Ridge

Au+Au 200GeV data - fit (except same-side peak)

\[ p_T > 0.15 \text{ GeV} \]

- Rapid transition from 55-65% to 46-55%
- Small change to most central after transition
- Ridge may be phenomena of underlying event

Ridge and Jet $\Delta \phi$ correlations with respect to Reaction Plane

- **Jet** = $(|\Delta \eta|<0.7)$ - Accep*$(|\Delta \eta|>0.7)$
- $|\Delta \eta|>0.7$ = near-side ridge + away-side
- Flow subtraction by ZYAM

STAR Preliminary Feng, QM’08; Konzer, QM’09; FW, SQM’09.

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Ridge correlations have reaction plane dependence

STAR Preliminary Feng, QM’08; Konzer, QM’09; FW, SQM’09.

(a) $3<p_T^{(t)}<4\text{ GeV/c}, 1<p_T^{(a)}<2\text{ GeV/c}$
- jet $(\Delta\phi<1.0, |\Delta\eta|<0.7)$
- ridge $(\Delta\phi<1.0, |\Delta\eta|>0.7)$

$|\phi_s| = \phi_{\text{trig}} - \psi_{\text{RP}}$
Correlated Emission Model (CEM)

Chiu, Hwa, arXiv:0809.3018

Asymmetric ridge peak predicted
Ridge and Jet $\Delta \phi$ correlations with respect to Reaction Plane

- **Jet** = ($|\Delta \eta| < 0.7$) - Accep*(|$\Delta \eta$| > 0.7)
- |$\Delta \eta$| > 0.7 = near-side ridge + away-side
- Flow subtraction by ZYAM
- 2 Gaussian fit to away side and subtracted
  
  - Ridge obtained

**STAR Preliminary** Konzer, QM’09; FW, SQM’09.
Au+Au 20-60%, $p_{\text{Trig}}=3-4$ GeV/c, $p_{\text{Assoc}}=1-1.5$ GeV/c

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Near side peak asymmetry

- Jet shape is symmetric
- Ridge is asymmetric!
  - shift to $\Delta \phi > 0$ side
- Ridge may come from jet-flow alignment
Back to Back Ridge

- Jet = (|Δη|<0.7) - Accep*(|Δη|>0.7)
- |Δη|>0.7 = near-side ridge + away-side
- Flow subtraction by ZYAM
- Fit: Back-to-Back Ridge + away conical emissions

STAR Preliminary Konzer, QM’09; FW, SQM’09.
Au+Au 20-60%, 3<p_{T, trig}<4, 1<p_{T, assoc}<2 GeV/c
Triangular Flow

PHOBOS inclusive
$2<\Delta\eta<4$

STAR inclusive
$1.2<\Delta\eta<1.9$

$N_{\text{Part}} = 91, \varepsilon_3 = 0.53$

$\varepsilon_3 \equiv \sqrt{\frac{\langle r^2 \cos(3\phi_{\text{part}}) \rangle^2 + \langle r^2 \sin(3\phi_{\text{part}}) \rangle^2}{\langle r^2 \rangle}}$

- Triangular flow is possible source of ridge!

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Comparison of AMPT and STAR

- $v_2 = \langle \cos(2(\phi - \psi_2)) \rangle \propto \varepsilon$
- $v_3 = \langle \cos(3(\phi - \psi_3)) \rangle \propto \varepsilon_3$

- $v_2$ & $v_3$ are depending on initial geometry in AMPT
- AMPT simulations have good consistency with data at $p_T > 0.8\text{GeV}$
$v_n\{EP\}$ at mid-rapidity with forward $\Phi_n$

200GeV Au+Au $\rightarrow$ charged particles ($|\eta|<0.35$)

- $\Phi_n^{RXN}$ ($|\eta|=1.0\ldots2.8$)
- $\Phi_n^{MPC}$ ($|\eta|=3.1\ldots3.7$)
- $\Phi_n^{BBC}$ ($|\eta|=3.1\ldots3.9$)

PHENIX Preliminary

Systematic errors are defined by the variations with $\Phi_n$ from different $\eta$ and from different methods including central-forward 2-particle correlation. Therefore it could include some physics biases.
Δη correlations with respect to trigger η

- Jet and Ridge property as function of trigger η
  - Back/Forward asymmetry of correlation shapes
  - Gradient of correlation functions
PYTHIA8

pythia8 : Ryo Funato

eta like sign correlation trig_eta_id:1

eta like sign correlation trig_eta_id:2

eta like sign correlation trig_eta_id:3

eta like sign correlation trig_eta_id:4

eta like sign correlation trig_eta_id:5

eta like sign correlation trig_eta_id:6

\[ \Delta \eta = \eta_{asso} - \eta_{trig} \]

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AMPT

Near side: $|\Delta \phi| < \pi/4$  
Flow Not Subtracted

$C_2$: arbitrary unit

$\eta_{\text{trig}} = -2.0$

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$\eta_{\text{asso}} - \eta_{\text{trig}} : [-4, +4]$

$\Delta \eta = \eta_{\text{asso}} - \eta_{\text{trig}}$

$\eta_{\text{trig}} = 0$

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$\eta_{\text{trig}} = 2.0$
PHENIX Data Analysis

- Trigger “sign” selection: “$\eta<0$” and “$\eta>0$”
- Precise trigger selection: [-0.35,0.35] 14 bins. 0.05 step.

- $\Delta \eta$ correlations: projected from $\Delta \phi - \Delta \eta$ correlations
  - Near side: $|\Delta \phi| < \pi/4$
  - Away side: $|\Delta \phi - \pi| < \pi/4$

- Superposition of jet and ridge due to central arm accep. $|\eta|<0.35$
Trigger $\eta$ sign selected correlations

$\eta > 0$

$\eta < 0$
Projected $\Delta \eta$ correlations: Trigger $\eta$ sign selected

Near: $|\Delta \phi| < \pi/4$

Away: $|\Delta \phi - \pi| < \pi/4$
Near side $\Delta \eta$ correlations: precise trigger selection

PHENIX preliminary

Near: $|\Delta \phi|<\pi/4$
Away side $\Delta \eta$ correlations: precise trigger selection

Away: $|\Delta \phi - \pi| < \pi/4$
Backward / Forward asymmetry

\[ \text{Yield Ratio} = \frac{\text{Avg}_{\text{Forward}} - \text{Avg}_{\text{Backward}}}{\text{Avg}_{\text{Forward}} + \text{Avg}_{\text{Backward}}} \]

- Forward: \( 0 < \Delta \eta < 0.25 \)
- Backward: \(-0.25 < \Delta \eta < 0 \)

- YR=0: symmetric shape
- YR>0 or <0: shift for Forward or Backward direction

“Forward” : \( \Delta \eta > 0 \)
“Backward” : \( \Delta \eta < 0 \)

Centrality: 0~20
trigger (hadron): Pt 2~4GeV
\( \eta_{\text{trig}} [0, 0.05] \)
associate (hadron): Pt 1~2GeV
Backward / Forward asymmetry: trigger sign selection

- Degree of asymmetry
  - at most $2\sigma$ in peripheral at near side
  - at most $1\sigma$ in peripheral at away side

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Backward / Forward asymmetry: trigger precise selection

- Large statistical & systematic error on both near and away side

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Gradient of correlations as function of trig $\eta$

- Fitting function: $[0] + [1]*x$
- Fitting range
  - $\Delta\eta : [0, 0.35]$ if $\eta_{\text{trig}} < 0$
  - $\Delta\eta : [-0.35, 0]$ if $\eta_{\text{trig}} < 0$

Centrality: 0~20
trigger (hadron): Pt 2~4GeV
$\eta_{\text{trig}} [0, 0.05]$
associate (hadron): Pt 1~2GeV
Gradient of correlations seems to be flat at near side

Away side also seems to be flat though still large statistical error
Correlations in high multiplicity p+p events at LHC-CMS

Minimum Bias
no cut on multiplicity

High multiplicity data set
and N > 110

(a) MinBias, $p_T > 0.1 \text{GeV/c}$

(c) $N > 110$, $p_T > 0.1 \text{GeV/c}$

The peak is truncated in both distributions

Back-to-back jet correlations enhanced in high multiplicity sample.

CERN Seminar, Sept. 21, 2010
CERN-PH-EP/2010-031
arXiv:1009.4122v1

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Minimum Bias
no cut on multiplicity

High multiplicity data set
and N>110

CMS, CERN Seminar, Sept. 21, 2010
CERN-PH-EP/2010-031
arXiv:1009.4122v1

(b) MinBias, 1.0GeV/c<\(p_T<3.0\)GeV/c

(d) N>110, 1.0GeV/c<\(p_T<3.0\)GeV/c

New “ridge-like” structure extending to large \(\Delta \eta\) at \(\Delta \phi \sim 0\)
Data and PYTHIA8

Increasing $p_T$

“Ridge” maximal for highest multiplicity and $1 < p_T < 3$ GeV/c

CERN Seminar September 21 2010
Other simulation models

PYTHIA D6T MinBias, N>70
PYTHIA D6T, Dijet 80-120GeV

HERWIG++, N>110
Madgraph, Dijet 100-250GeV, N>90

1<p_T<3 GeV/c

No ridge effect in these models (with the tunes used)
Data and PYTHIA D6T at 0.9, 2.36 and 7 TeV

(a) CMS $\sqrt{s} = 0.9\text{TeV}$  
(b) CMS $\sqrt{s} = 2.36\text{TeV}$  
(c) CMS $\sqrt{s} = 7\text{TeV}$

PYTHIA D6T  
PT inclusive

(a) PYTHIA $\sqrt{s} = 0.9\text{TeV}$  
(b) PYTHIA $\sqrt{s} = 2.36\text{TeV}$  
(c) PYTHIA $\sqrt{s} = 7\text{TeV}$
Comparison 7 TeV p+p and 200 GeV Cu+Cu correlations

High multiplicity data set N>110

- Correlations in Cu+Cu at similar multiplicity dominated by flow.
- How correlation shape changed if $v_2$ exists in high mult. p+p event?
- Need to survey azimuthal dynamics in high mult. p+p events
Accumulative azimuthal correlations

\[ \langle \sum_i \cos(\phi_{\text{trig}} - \phi_{\text{asso}}^i) \rangle = \text{Mult} \cdot v_2 \left( p_{T\text{trig}} \right) v_2^{\text{asso}} + \{\text{non-flow}\} \]

\[ 0.15 < p_{T\text{asso}} < 2.0 \text{GeV/c at } |\eta| < 1.0 \]

- Consistent with p+p minimum bias at peripheral
- Enhance of Au+Au correlations at mid central & central by flow-like component
- Method to search the possible modification in high multiplicity p+p events from minimum bias because no event plane needed
Accumulative correlations in high multiplicity p+p events at 200 GeV

- Enhance in mid-rapidity high multiplicity event
- Azimuthal dynamics in p+p events depends on multiplicity if track number count and calculation done in same rapidity range.
Possible ridge in p+p collisions at RHIC energy?

- data to analyze: 500GeV, 200GeV and 62.4 GeV
Summary

• Overview of basic ridge property
• Ridge study via $\Delta \phi$ correlations with respect to Reaction Plane
  – Ridge depends on Reaction Plane
• Triangular flow
  – Possible source of ridge
  – AMPT well describes STAR experimental data at $p_T > 0.8$GeV
• $\Delta \eta$ correlations with respect to trigger $\eta$
  – No trigger $\eta$ dependence seen in PHENIX acceptance…
• Ridge in high multiplicity p+p events at LHC-CMS
Back Up Slides
Structure of AMPT v1.xx (default model)

A+B

HIJING (parton PDFs, nuclear shadowing):  
minijet partons,  
excited strings,  
spectators

Little partonic interactions;

ZPC (Zhang's Parton Cascade)

Partons freeze out

Dominated by hadronic interactions  
(at very high densities)

Hadronization (Lund String)

ART (A Relativistic Transport model for hadrons)

Hadrons freeze out (before a cut-off time);  
strong-decay all remaining resonances

Final particle spectra
Structure of AMPT v2.xx (String Melting model)

A+B

HIJING (parton PDFs, nuclear shadowing):
- minijet partons,
- excited strings,
- spectators

Melt to partons via intermediate hadrons

ZPC (Zhang's Parton Cascade)

Partons freeze out

Hadronization (Quark Coalescence)

ART (A Relativistic Transport model for hadrons)

Hadrons freeze out (before a cut-off time); strong-decay all remaining resonances

Final particle spectra
None trigger selected $\Delta \phi - \Delta \eta$ correlations

Run7 Au+Au 200GeV Centrality 0-20%
Trigger $h$ $p_t$ : 2-4GeV
No trig. select.
Associate $h$ $p_t$ : 1-2GeV
$v_2$ and $v_3$ subtracted

Run7 Au+Au 200GeV Centrality 20-50%
No trig. select.

Run7 Au+Au 200GeV Centrality 50-93%
No trig. select.
