Jet and Flow analysis at RHIC and LHC

ShinIchi Esumi
Inst. of Physics, Univ. of Tsukuba

Source size/shape measurement with HBT
Energy loss and jet quenching
Small but high multiplicity system
Interplay between soft and hard
relation to collective event anisotropy
Source geometry (size, shape and time duration) at the end of freeze-out via two particle quantum interferometry (HBT measurement)

\[ R_{T\text{-side}}, R_{T\text{-out}} \text{ vs } (\phi-\Phi_2), (\phi-\Phi_3) \]
\[ R_{T\text{-side}} \text{ oscill.} < R_{T\text{-out}} \text{ oscill. for } n=2,3 \text{ (central)} \]

Together with \( v_n(p_T)^{\text{PID}} \) fitting with Blast Wave

PHENIX Preliminary, QM12

Au+Au 200GeV 0-10%
Initial vs Final spatial anisotropy

extracted by BW fitting with spectra + $v_{2,3,4}$ of $\pi,K,p$

$T_f$: temperature at freeze-out
$\rho_0$: average velocity
$\rho_n$: anisotropic velocity
$s_n$: spatial anisotropy

extracted from $R_{T_{side}}$ by $\pi\pi$ HBT

Au+Au 200GeV

PHENIX, QM12
Energy loss (jet quenching) in QGP


central Au+Au

arXiv: 1208.2254

PRL109, 152302 (2012)

23/Jun/2013, Matsumoto

Shinichi Esumi, Univ. of Tsukuba
\[ A_J = \frac{E_{T_1} - E_{T_2}}{E_{T_1} + E_{T_2}} \]

\[ E_{T_1} > 100 \text{ GeV} \]

\[ E_{T_2} > 25 \text{ GeV} \]

Di-jet asymmetry : \( A_J \)

Re-distribution of the lost energy from the jet quenching

LHC-CMS, PRC84 (2011) 024906

Missing $p_T^{\parallel}$: $p_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos(\phi_{\text{Track}} - \phi_{\text{Leading Jet}})$

0-30% Central PbPb

Out of the jet cones
Excess towards sub-leading jet

Inside the jet cones
Excess towards leading jet

All tracks
Tracks in the jet cone $\Delta R<0.8$
Tracks out of the jet cone $\Delta R>0.8$
Use photons, Jets, single hadrons as trigger in order to look at correlated association emission.

Multi-particle correlation like 2+1 particle correlation correlation analysis (Trig1, Trig2, Asso) can be used as largely modified jet and di-jet signal.

Use “Trig2 relative to Trig1” as jet trigger condition, and look at distribution: “Associate relative to Trig1” without jet-reconstruction bias.
Background Fluctuation in Jet energy

$$p_T^{\text{Jet}} = p_T^{\text{rec. Jet}} - \rho \text{ Area}^{\text{rec. Jet}}$$

Area($\pi R^2$)$\sim 0.5$ for $R \sim 0.4$

$$\delta p_T = \Sigma_{\text{ran.}} (p_T - \rho A)$$

LHC-ALICE, JHEP03 (2012) 053
Event plane and pT threshold effects on Jet energy determination

LHC-ALICE, JHEP03 (2012) 053
Energy resolution of Jet energy

Figure 1: Results of MC evaluation of jet reconstruction performance in 0–10% and 60–80% collisions as a function of truth jet $E_T$ for $R = 0.2$ (left) and $R = 0.4$ (right) jets. Top: jet energy resolution $\sigma[\Delta E_T]/E_T^{\text{truth}}$ and jet energy scale closure, $\langle \Delta E_T \rangle/E_T^{\text{truth}}$. Solid curves show parameterizations of the JER using Eq. 4. Bottom: Efficiencies, $\varepsilon$ and $\varepsilon'$, for reconstructing jets before and after application of UE jet removal (see text for explanation), respectively.
Jet cone radius dependence of fluctuation


Figure 2: Top: Representative distributions of $E_T^{3\times4} - \langle E_T^{3\times4} \rangle$ (left) and $E_T^{7\times7} - \langle E_T^{7\times7} \rangle$ (right) (see text for definitions) for data (points) and MC (filled histogram) for Pb+Pb collisions with $3.4 \leq \Sigma E_{T}^{FCal} < 3.5$ TeV. The vertical lines indicate $E_T^{3\times4} - \langle E_T^{3\times4} \rangle = 0$ and $E_T^{7\times7} - \langle E_T^{7\times7} \rangle = 0$. Bottom: Standard deviations of the $E_T^{3\times4}$ and $E_T^{7\times7}$ distributions, $\sigma[E_T^{3\times4}]$ and $\sigma[E_T^{7\times7}]$, respectively, in data and HIJING MC sample as a function of $\Sigma E_{T}^{FCal}$. 

Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV $\int L \, dt = 240$ mb$^{-1}$ 

23/Jun/2013, Matsumoto

Shinichi Esumi, Univ. of Tsukuba
Figure 3: Top: Measured and corrected $R_{\text{CP}}$ values for the 0–10% centrality bin as a function of jet $p_T$ for $R = 0.4$ and $R = 0.2$ jets. Bottom: Ratio of corrected to measured $R_{\text{CP}}$ values for both jet radii. The error bars on the points represent statistical uncertainties only.

Figure 8: Ratios of $R_{\text{CP}}$ values between $R = 0.3, 0.4$ and $0.5$ jets and $R = 0.2$ jets as a function of $p_T$ in the 0–10% centrality bin. The error bars show statistical uncertainties (see text). The shaded boxes indicate partially correlated systematic errors. The lines indicate systematic errors that are fully correlated between different $p_T$ bins.
A small but high-temperature/density system might be created in high multiplicity pp and pA collisions...
Are they collective/expanding?
2 particle correlation w.r.t. collision geometry and expansion

- strong $\Phi_2$ dependence and left/right asymmetry (coupled with energy loss and flow)
- broad out-of-plane correlation enhanced more in central (redistribution and expansion)
- weak $\Phi_3$ dependence

PHENIX Preliminary, QM12
Au+Au 200GeV, hadron-hadron $p_T$: $(2\sim4)_{\text{Trig}} \times (1\sim2)_{\text{ASSO}}$ (GeV/c)
\[ Y(\mid \Delta \eta \mid > 0.7) = \text{Ridge} + \text{away-side two-Gaussian} \]

\[ \text{Jet} = Y(\mid \Delta \eta \mid < 0.7) - \text{Acceptance} \times Y(\mid \Delta \eta \mid > 0.7) \]
Associate yield per trigger with AMPT simulation

Look at asymmetry in $\Delta \eta = \eta^{\text{Asso}} - \eta^{\text{Trig}}$ associate $\eta$ distribution with respect to trigger $\eta$
Summary

Source size/shape measurement with HBT
Energy loss and jet quenching
Small but high multiplicity system
Interplay between soft and hard
relation to collective event anisotropy
Correlations relative to $\Psi_2$ & $\Psi_3$, 40-50%

Au+Au 200GeV, 40-50%, 2-4\textcircled{1}-2 GeV, $\nu_2 \nu_3 \nu_4(\Psi_4)$ subtracted with $<\cos 4(\Psi_2 - \Psi_4)> = \nu_4(\Psi_2)/\nu_4(\Psi_4)$ by ZYAM

PHENIX, QM12

mid-central collisions

- strong $\Phi_2$ dependence and left/right asymmetry coupling with geometry and/or expansion
- almost no $\Phi_3$ dependence (poor $\Phi_3$ resolution)

23/Jun/2013, Matsumoto

Shinichi Esumi, Univ. of Tsukuba
Correlations relative to $\Psi_2$ & $\Psi_3$, 0-10%

Au+Au 200GeV, 0-10%, 2-4\#1-2 GeV, $v_2 \Psi_3^4(v_4^4)$ subtracted with $<\cos 4(v_2^2 v_4^4)> = v_4^4(v_2^2 v_4^4)$ by ZYAM

PHENIX, QM12

central collisions

- out-of-plane correlation enhanced
  (strong jet quenching and collective expansion)
- some weak $\Phi_3$ dependence

23/Jun/2013, Matsumoto

Shinichi Esumi, Univ. of Tsukuba
Y(|Δη|>0.7) = **back-to-back 2 ridges** + away-side two-(left/right) Gaussian