High $p_T$ suppression and $v_2$ from PHENIX
ShinIchi Esumi, Univ. of Tsukuba

Contents
- High $p_T$ suppression
- $v_2$ and higher harmonics
- HBT w.r.t. $\phi_n$
- Jet correlation w.r.t. $\phi_n$
(Non-) suppression of hadron (direct-photon)

- strong suppression of hadrons
- no suppression of direct photons at high $p_T$
Thermal photons and their Flow

- significant low $p_T$ photon excess
- comparable $v_2$ with hadrons

$d+Au$

$Au+Au$

- External conversions (PHENIX preliminary)

arXiv: 1208.1234


arXiv: 1105.4126

PHENIX QM12
Energy dependence of hadron suppression from low RHIC energy to LHC energy

- smaller suppression (or enhancement) at low energy
- saturation at high energy

![Graph showing energy dependence of hadron suppression](image)

*arXiv: 1204.1526*

High pT physics at LHC, Wuhan, China, 23/Oct/2012
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Fractional energy loss

- continuous increase of energy loss in terms of fractional energy loss in $p_T$ (coming from slope changes)

Au+Au, Most central 0-10%

- 200 GeV
- 62.4 GeV
- 39 GeV

Pb+Pb 0-5%, $\delta$ (global)=0.3%
Au+Au 0-5%, $\delta$ (global)=1.0%
Pb+Pb 70-80%, $\delta$ (global)=0.7%
Au+Au 70-80%, $\delta$ (global)=2.9%

ALICE
2.76 TeV

PHENIX
200 GeV

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$R_{AA}$ and $v_2$ from RHIC to LHC

- no simple solution to describe $R_{AA}$ and $v_2$ for both RHIC/LHC simultaneously
Deviation from $n_{CQ}$ scaling at 200GeV $Au+Au$

- consequence of similar $v_2$ at high $p_T$ for different particle species
Central collisions (193GeV U+U) at RHIC

- larger radial flow
- various geometry tests on going with Cu+Au, U+U data from run12.
Beam energy dependence for identified particle $v_2$ and $v_3$ - similar for all particle species
Blast Wave fitting and $n_{CQ}$ scaling of identified particle $v_n$

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(a) : $\sim v_2 / n_{CQ}$
(b) : $\sim v_n^{1/n}$
(a)+(b) : $\sim v_n / n_{CQ}^{n/2}$

- anisotropy in velocity, coordinate
- $T_f$ and $\rho_0$ constrained by spectra

$T_f$ : temperature at freeze-out
$\rho_0$ : average velocity
$\rho_n$ : anisotropic velocity
$s_n$ : spatial anisotropy
Azimuthal HBT of $\pi\pi$, KK


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$R_{T\text{-side}}, R_{T\text{-out}} (\phi - \Phi_2)$

$R_{T\text{-side}}, R_{T\text{-out}} (\phi - \Phi_3)$

**PHENIX, QM12**

**Au+Au 200GeV 0-10%**

$R^2_{T\text{-side}} < R^2_{T\text{-out}}$ oscill. for $n=2,3$ (central)

*Initial spatial fluctuation (triangularity)*

*Momentum anisotropy triangular flow $v_3$*
**Initial vs Final spatial anisotropy**

- **$S_2$, $S_3$, $S_4$**
  - 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

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**Au+Au 200GeV**

- Extracted from $R_{\text{side}}$ by $\pi\pi$ HBT

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2-part. $\Delta \phi$ correlation with various flow subtraction (1)

$\Delta \phi = \phi_{asso} - \phi_{trig}$ [rad]

- $v_3$ is largely responsible for away side “mach-cone” like shape
2-part. $\Delta \phi$ correlation with various flow subtraction (2)

$1/N_{tr} dN_{pair} / d\Delta \phi$

$0-10\%$

$40-50\%$

$v_2 v_3$

$v_2 v_3 v_4 (\Psi_2)$

$v_2 v_3 v_4 (\Psi_4)$

- but $v_4 \{\Phi_4\}$ matters!

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Correlations relative to $\Psi_2$ & $\Psi_3$, 40-50%

Au+Au 200GeV, 40-50%, 2-4×1-2 GeV, $v_2 v_3 v_4(\Psi_4)$ subtracted with $<\cos(\Psi_2-\Psi_4)>=v_4(\Psi_2)/v_4(\Psi_4)$ by ZYAM

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mid-central
- strong $\Phi_2$ dependence and left/right asymmetry coupling with geometry and/or expansion
- almost no $\Phi_3$ dependence (poor $\Phi_3$ resolution)
Correlations relative to $\Psi_2$ & $\Psi_3$, 0-10%  

Au+Au 200GeV, 0-10%, 2-4 \& 1-2 GeV, $v_2 v_3 v_4(\Psi_4)$ subtracted with $<\cos 4(\Psi_2 - \Psi_4)> = v_4(\Psi_2)/v_4(\Psi_4)$ by ZYAM

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

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Summary

• High $p_T$ suppression
• $v_2$ and higher harmonics
• HBT w.r.t. $\Phi_n$
• Jet correlation w.r.t. $\Phi_n$
Centrality and $p_T$ dependences of $v_n$ at 200GeV Au+Au

$\sqrt{s_{NN}} = 200$GeV

$v_3$ is comparable to $v_2$ at 0~10% weak centrality dependence on $v_3$

$v_4(\Phi_4) \sim 2 \times v_4(\Phi_2)$

All of these are consistent with initial fluctuation.
How the initial geometrical anisotropy was transformed into the final momentum anisotropy?
Small deviations in \(\frac{m_T-m_0}{n_q}\) scaled \(v_2\)

Pb+Pb 2.76TeV

roughly \(\frac{m_T-m_0}{n_q}\) scaled for all energies
larger \(p_T\) shift for heavier particles
radial flow increases with energy

M. Krzewicki, QM11
Au+Au 200GeV, $p_T^t \otimes p_T^a = 2-4 \otimes 1-2$ GeV

$V_2 V_4(\Psi_2)$

$V_2 V_3$

$V_2 V_3 V_4(\Psi_2)$

$V_2 V_3 V_4(\Psi_4)$

$V_1^{EP \, flp} V_2 V_3 V_4(\Psi_4)$

$V_1^{2PC} V_2 V_3 V_4(\Psi_4)$
Correlations relative to $\Psi_2$ & $\Psi_3$ 20-30%