Spectra of identified particles, geometry categorization and bias and global observables in d+Au Collisions

Sarah Campbell
for the PHENIX Collaboration
5/19/2014
Quark Matter
Darmstadt, Germany
Outline

• Why discuss d+Au centrality?
• How do we determine centrality, global observables & geometry?
  – Correcting for auto-correlation bias
• What is interesting in d+Au with centrality?
  – Identified particle results
• Conclusions/Future
Why discuss d+Au centrality?

Last Quark Matter:

Unclear how much of the $R_{CP}$ is due to suppression in central d+Au versus an enhancement in peripheral d+Au.

$\pi^0 \ R_{dA}$ will be shown.

PHENIX Preliminary

d+Au, $\sqrt{s_{NN}} = 200$ GeV

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Why discuss d+Au centrality?

Last Quark Matter: An auto-correlation bias effect?

An auto-correlation bias effect?
Why discuss d+Au centrality?

\( p_T \) dependence of multiplicity effect in the auto-correlation bias

- Review centrality determination
- Review auto-correlation bias correction
- Discuss \( p_T \) dependence
$-3.9 < \eta < -3.0$

$\text{BBC Charge}_{\text{Au-going}}$

$\text{BBC Charge}_{\text{Au}} \propto N_{\text{Coll}}$

$N_{\text{Coll}}, N_{\text{Part}}, b, \text{etc.}$

Number of participating nucleons

Number of binary collisions

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$-3.9 < \eta < -3.0$

**Observable**

BBC Charge$_{\text{Au-going}}$

**Map**

Geometry, global information

$N_{\text{Coll}}, N_{\text{Part}}, b, \text{etc.}$

**Glauber Monte Carlo**

- $d$: Hulthen $\psi(r)$
- $\text{Au}$: Woods-Saxon $\rho(r)$

$$\text{BBC Charge}_{\text{Au}} \propto N_{\text{Coll}}$$

arXiv:1310.4793

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Systematic Uncertainties

81 variations of parameters
n-tagged Cross Check

Good agreement

η > 5

Counts

Single neutron

Exponential background

Double interactions

ZDC Energy (d-going direction) [GeV]

Neutron-Tag Fraction

Glauber Monte Carlo

n-tagged data

d+Au @ 200 GeV

arXiv:1310.4793

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Auto-correlation Bias

In p+p  Trigger biased to non-diff. events $\rightarrow$ more mid-y particles

\[
\frac{\epsilon_{\text{mid-y}}^{p+p}}{\epsilon_{\text{BBC}}^{p+p}} = \frac{75 \pm 3\% \text{ of particles}}{52 \pm 4\% \text{ of events}}
\]

\[
\sigma_{MB}^{pp} = \sigma_{\text{non-diff}} + \sigma_{1\text{-diff}} + \sigma_{2\text{-diff}}
\]

From Pythia:  $42mb = 28mb + 10mb + 4mb$

Primarily produces particles at mid-rapidity
Auto-correlation Bias

In p+p
Trigger biased to non-diff. events → more mid-y particles

\[
\frac{\epsilon_{\text{mid-y}}^{p+p}}{\epsilon_{MB}^{p+p}} = \frac{75 \pm 3\% \text{ of Particles}}{52 \pm 4\% \text{ of Events}}
\]

In d+Au
Trigger bias

Effect in peripheral collisions, low \( \epsilon_{MB} \) → too high

arXiv:1310.4793
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Auto-correlation Bias

\[ \frac{\varepsilon_{\text{mid-}y}^{p+p}}{\varepsilon_{\text{BBC}}^{p+p}} = \frac{75 \pm 3\% \text{ of Particles}}{52 \pm 4\% \text{ of Events}} \]

**In p+p**
- Trigger biased to non-diff. events \( \rightarrow \) more mid-\( y \) particles

**In d+Au**
- Trigger bias **AND** Multiplicity effect
  - Peripheral \( \frac{\text{Particles}}{\text{Event}} \) too high
  - Events with mid-\( y \) particles have higher multiplicity

Lose high multiplicity events, Decrease \( \frac{\text{Particles}}{\text{Event}} \)

Gain high multiplicity events, Increase \( \frac{\text{Particles}}{\text{Event}} \)

A hard interaction deposits 1.55 x charge in the BBC

arXiv:1310.4793
Auto-correlation Bias

\[ \frac{\epsilon_{\text{mid-}y}^{p+p}}{\epsilon_{\text{BBC}}^{p+p}} = \frac{75 \pm 3\% \text{ of } \text{Particles}}{52 \pm 4\% \text{ of } \text{Events}} \]

In p+p: Trigger biased to non-diff. events \(\rightarrow\) more mid-\(y\) particles

In d+Au: Trigger bias \textbf{AND} Multiplicity effect

Correction factor, \(c\)

\[ R_{dA} = \frac{c \, \frac{dN^{d+Au}}{dy}}{\langle N_{\text{Coll}} \rangle \frac{dN^{p+p}}{dy}} \]

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Competing effects
- Trigger bias: 0.89
- Multiplicity effect: 1.16

Multiplicity effect only

These corrections are in all of our d+Au publications, both the 2003 and 2008 data

arXiv:1310.4793

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p_T Dependence of Multiplicity Effect

PHENIX Data p+p @ 200 GeV
- p+p inclusive (42 mb)
- p+p with particle p_T > 1.5 GeV/c
- p+p with \pi^0 at given p_T

arXiv:1310.4793
p_T Dependence of Multiplicity Effect

Model with Hijing

\[
c = \frac{\text{true sim. yield/event}}{\text{measured sim. yield/event}}
\]

PHENIX Data p+p @ 200 GeV
- p+p inclusive (42 mb)
- p+p with particle \( p_T > 1.5 \text{ GeV/c} \)
- p+p with \( \pi^0 \) at given \( p_T \)

RHIC

Hijing p+p \( \sqrt{s} = 200 \text{ GeV} \)

\(-3.9 < \eta < -3.0\)
p_T Dependence of Multiplicity Effect

Model with Hijing

\[ c = \frac{\text{true sim. yield/event}}{\text{measured sim. yield/event}} \]

vary < 5%

PHENIX Data p+p @ 200 GeV

- p+p inclusive (42 mb)
- p+p with particle p_T > 1.5 GeV/c
- p+p with \( \pi^0 \) at given p_T

ARXIV:1310.4793

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**p_T Dependence of Multiplicity Effect**

**Model with Hijing**

\[ c = \frac{\text{true sim. yield/event}}{\text{'measured' sim. yield/event}} \]

**LHC**

HIJING \( p+p \quad \sqrt{s} = 5.02 \text{ TeV} \)

\(-4.9 < \eta < -3.1\)

**RHIC**

HIJING \( p+p \quad \sqrt{s} = 200 \text{ GeV} \)

\(-3.9 < \eta < -3.0\)

**Much larger effect at LHC!**

arXiv:1310.4793

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What causes the RHIC/LHC difference?

- Multiparton interactions
  - 0.24 in 200 GeV d+Au
  - 1.36 in 5.02 TeV p+Pb

\(\sqrt{s_{NN}}\) dependence

arXiv:1310.4793

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What causes the RHIC/LHC difference?

- Multiparton interactions
  - 0.24 in 200 GeV d+Au
  - 1.36 in 5.02 TeV p+Pb

RHIC auto-correlation bias is well understood & under control

Hijing

\( N_{\text{coll}} \) shape dependence

\( \sqrt{s_{\text{NN}}} \) dependence
Mini-summary

- $p_T$ dependence of multiplicity effect is within the uncertainty of auto-correlation bias correction
- Auto-correlation factors correct for this bias
- $\pi^0 + \text{jet } R_{CP}$ is robust
  - Can not be described solely by auto-correlation bias in Hijing

Next: Nuclear Modification of identified hadrons in d+Au
  - $\pi$, K, p, $K_S^0$, $K^*$
Nuclear modification factor in d+Au

Consistent with $N_{\text{Coll}}$-scaled p+p

arXiv:1405.3628
Nuclear modification factor in d+Au

Hint of suppression at high $p_T$

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

$R_{dAu}$ vs. $p_T$ [GeV/c] for 0-20% and 60-88% centrality bins.

Legend:
- $\pi^0$
- $K^0$
- $K_S$
- $\phi$
- $\bar{p}+p$

arXiv:1405.3628

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Nuclear modification factor in d+Au

Baryons enhanced in central d+Au

arXiv:1405.3628
Nuclear modification factor in d+Au

Baryons enhanced in central d+Au

Recombination in d+Au?

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Nuclear Modification Factors

Baryon enhancement increases with d+Au centrality

PRC 88, 024906 (2013)
Nuclear Modification Factors

Suppression increases with Au+Au centrality

PRC 88, 024906 (2013)
Nuclear Modification Factors

Protons are suppressed in Au+Au relative to 0-20% d+Au

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Compare 60-92% Au+Au and 0-20% d+Au

Energy loss in peripheral Au+Au?

or

Effect of rapidity shift in particle production?

or

Hydrodynamic effect?

No $N_{\text{coll}}$-scaling applied

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<td>Au+Au 60-92%</td>
<td>14.8 ± 3.0</td>
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<td>d+Au 0-20%</td>
<td>15.1 ± 1.0</td>
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PRC 88, 024906 (2013)
Conclusions

• Auto-correlation bias well understood
  – $\pi^0$ + jet $R_{CP}$ not described by auto-correlation bias in Hijing

• Baryon enhancement in d+Au
  – Peripheral d+Au consistent with $N_{Coll}$-scaled p+p
  – Recombination in central d+Au?

• Future
  – Run14: $^3$He+Au
  – Run15: p+Au, p+Si
  – How to interpret behavior of $\frac{60-92\% \text{ Au}+\text{Au}}{0-20\% \text{ d}+\text{Au}}$?
Backup
Observable

- $-3.9 < \eta < -3.0$

**BBC Charge**$_{\text{Au-going}}$

**Geometry, global information**

- $N_{\text{Coll}}, N_{\text{Part}}, b, \text{ etc.}$

**Map**

**BBC Charge**$_{\text{Au}} \propto N_{\text{Coll}}$

- MB trigger turn on curve

Glauber Monte Carlo
- $d$: Hulthen $\psi(r)$
- Au: Woods-Saxon $\rho(r)$

arXiv:1310.4793

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Systematic Uncertainties

81 variations of parameters

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<th>Default</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td>$\sigma_{NN}$</td>
<td>42mb</td>
<td>39mb</td>
<td>45mb</td>
</tr>
<tr>
<td>$W - S$ $\rho(r)$</td>
<td>R = 6.38 fm a = 0.54 fm</td>
<td>Less dense R = 6.65 fm a = 0.55 fm</td>
<td>More dense R = 6.25 fm a = 0.53 fm</td>
</tr>
<tr>
<td>$N_{\text{Coll}}^\alpha$</td>
<td>$\alpha = 1$</td>
<td>$\alpha = 0.95$</td>
<td>$\alpha = 1.05$</td>
</tr>
<tr>
<td>$z$-vtx</td>
<td>&lt; 5 cm</td>
<td>-25-30 cm</td>
<td>25-30 cm</td>
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![Graph showing systematic uncertainties with 81 variations of parameters](image-url)
Where do these numbers come from?

In p+p

Trigger biased

\[
\frac{\epsilon_{\text{mid} - y}^{p+p}}{\epsilon_{\text{BBC}}^{p+p}} = \frac{75 \pm 3\% \text{ of Particles}}{52 \pm 4\% \text{ of Events}}
\]

Likelihood BBC trigger fires assuming 42mb \(\sigma_{\text{NN}}\)

Likelihood trigger fires from mid-\(y\) \(\pi^0\), charged hadron, J/\(\psi\)

In d+Au

Trigger bias AND Multiplicity effect

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Competing effects
- Trigger bias: 0.89
- Multiplicity effect: 1.16

Assume a hard interaction deposits 1.55 x charge in the BBC

Scale NBD accordingly for that interaction

Consider 1 hard interaction among the \(N_{\text{Coll}}\) in that event

Calculate yield with and without multiplicity effect to get correction

Trigger less efficient

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Hijing info

- Model BBC response and trigger
  - Full GEANT for each event, $O(10^9)$ events, takes too long
  - In p+p, require minimum of 1 particle in each BBC
    - 48% $\rightarrow$ 52 +/- 4% in data
  - In d+Au:
    - 83% $\rightarrow$ 88 +/- 4% in data, separated into centrality bins
- Model central arm response for $p_T > 1$ GeV mid-y particle
  - BBC multiplicity increase 1.62 $\rightarrow$ 1.55 in data
  - Trigger probability 62% $\rightarrow$ 75 +/- 3% in data
    - Because of 1-diff, 2-diff handling in Hijing?
- Get mid-y yield/event from simulated BBC ‘measured’ centrality bins $\rightarrow$ ‘measured’ value
  - Calculate $N_{\text{Coll}}$ from generator ‘truth’ info in these ‘measured’ bins
- Get mid-y yield/event from events in ‘truth’ centrality bins with the same $N_{\text{Coll}}$ $\rightarrow$ ‘truth’ value
$K_S^0$ and $K^{*0}$ in $d+Au$, Cu+Cu

$\pi^0$: Photon ID in EMC

Particle ID in TOF-E

arXiv:1405.3628
$\pi, K, p$ in $d+Au, Au+Au$
Time of Flight measurement

\[ m^2 = \frac{p^2}{c^2} \left( \frac{t^2 c^2}{L^2} - 1 \right) \]

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<th>Resolution</th>
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<td>Charged tracking</td>
<td>1.050</td>
</tr>
<tr>
<td>Multiple scattering</td>
<td>1.000</td>
</tr>
<tr>
<td>Total timing</td>
<td>0.095 (95ps)</td>
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- pID purity better than 90%

Au+Au 200 GeV

2σ bands

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Charge ratios

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<td>Centrality dependence</td>
<td>N.A.</td>
<td>X</td>
<td>X</td>
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<tr>
<td>$p_T$ dependence</td>
<td>✓</td>
<td>X</td>
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Isospin effect at high $p_T$
K/$\pi$ Ratio

Strangeness enhancement in Au+Au

No strangeness enhancement in d+Au
p/π Ratio

Baryon enhancement in Au+Au and d+Au

PRC 88, 024906 (2013)
Compare d+Au, Au+Au

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Similar particle production mechanisms in d+Au and peripheral Au+Au
\textbf{He}^3+\textbf{Au} provides an larger, intrinsic triangular collision geometry

backup