PHENIX Results On Small Systems

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3rd International Conference on the Initial Stages of Heavy Ion Collisions
Lisbon, May 22-27, 2016
Small Collision Systems

Flow

Jets
Flow Dynamics in A+A

- Similar flow dynamics at RHIC and the LHC
- Same hydro calculation for \( v_n \) measured at different collision energies
- Same underlying physics
The Hydrodynamic Picture

- Pre Equilibrium
- QGP Expansion
- Hadron Phase
The Hydrodynamic Picture

Pre Equilibrium → QGP Expansion → Hadron Phase

In Ideal Hydro

\[ V_2 \propto \varepsilon_2 \]
The Hydrodynamic Picture in Small Systems?

- Is it hot enough?
- Is it sufficiently long-lived?
Geometry Engineering at RHIC

Structure of the proton is important

Geometry dominated by elliptic/triangular shape.

ONLY AT RHIC

Courtesy of Björn Schenke
PHENIX Azimuthal Correlation and $v_n$ Measurements

$^3$He+Au


d+Au


p+Au

Preliminary Status
Long Range Azimuthal Correlations in $p + Au$

$|\Delta \eta| = 2.75$
Long Range Azimuthal Correlations

Central $^3$He+Au

Clear near-side ridge

Compare to p+p reference
Long Range Azimuthal Correlations

Central $^3$He+Au

$p+p$

Central $p+Au$

$p+Au$ 200GeV 0 - 5%

$1.0 < p_{T,\text{track}} < 3.0$ GeV/c

$|\eta_{\text{trigger}}| < 0.35$

$-3.9 < \eta_{\text{asso}} < -3.0$

PHENIX preliminary
Estimating Non-Flow

\[ C_2 (p_T) = C_2^{\text{Non-Elementary}} + C_2^{\text{Elementary}} \]
Estimating Non-Flow

\[ C_2(p_T) = C_2^{\text{Non-Elementary}} + C_2^{\text{Elementary}} \]

\[ C_2(p_T) = C_2^{\text{Non-Elementary}} + C_2^{p+p} \]

Charge at Forward \( \eta \) in \( p+p \)

Charge at Forward \( \eta \) in \( p+Au \)

Use \( p+p \) as a reference

Scale it down by relative multiplicity
Event Plane Method

\[ \nu_2 = \frac{\left\langle \sum \cos 2(\phi - \Psi_2) \right\rangle}{\text{Res} (\Psi_2)} \]

Resolution \( \text{Res} (\Psi) \) estimated from correlation of three independent sub-events
Elliptic Flow in p+Au

Asymmetric systematics account for non-flow contribution to $v_2$
Elliptic Flow in all Systems

\[ V_2 \]

- \(^3\text{He}+\text{Au} 200\text{GeV} 0-5\%
- \text{d}+\text{Au} 200\text{GeV} 0-5\%
- \text{p}+\text{Au} 200\text{GeV} 0-5\%

\( p_T \) [GeV/c]
Elliptic Flow in all Systems

\[ \varepsilon_2^{d+Au} \sim \varepsilon_2^{^{3}\text{He}+Au} > \varepsilon_2^{p+Au} \]

\[ V_2^{d+Au} \sim V_2^{^{3}\text{He}+Au} > V_2^{p+Au} \]
Elliptic Flow in All Systems

Good agreement with hydro!

Elliptic Flow Scaling?


Glauber+Hydro
Central Events
- p+Au
- d+Au
- ^3He+Au
Elliptic Flow Scaling?


Glauber+Hydro Central Events
- p+Au
- d+Au
- \( ^3 \text{He}+\text{Au} \)
Imperfect Elliptic Flow Scaling

Reproduced by hydrodynamics!
**IPGlasma Initial Conditions**

**MC Glauber**
- Fluctuations in nucleon coordinates
- Smear energy deposition by Gaussian
- Use all participants

**IPGlasma**
- Fluctuations in nucleon coordinates
- Fluctuations in color charge within nucleons
- Look at region where nucleons overlap

d+Au and $^3$He+Au are overpredicted
p+Au is underpredicted

$\eta/s = 0.12$
 Hydro + IPGlasma Initial Conditions

Changing $\eta/s$ makes all curves move in the same direction

$\eta/s = 0.18$

![Graph](image)
Partonic Scattering in AMPT


Reasonable agreement below ~1 GeV/c

MC Glauber Initial Geo

String Melting

Partonic Scattering $\sigma = 1.5 \text{ mb}$

Spatial Coalescence

Hadronic Scattering
Take-Home Message

Geometry drives flow in small systems

AMPT

d+Au Central Event

Hydro

d+Au Central Initial Condition
Going Down in Size and Energy

Other stages become relevant for small system collectivity

Pre Equilibrium → QGP Expansion → Hadron Phase

d+Au Beam Energy Scan + Model Comparisons
How Low Can You Go?

2+1D QGP Volume in Central d+Au

Volume $\times$ Time in QGP [fm$^2$ $\Delta t$/fm/c]

Center-of-Mass Energy [GeV]

2+1D QGP Volume in Central d+Au

Volume × Time in QGP [fm² ΔY fm/c]

Center-of-Mass Energy [GeV]

LHC

Oriueta, Koop, Belmont, Yin, Nagle, Phys. Rev. C 93, 044910 (2016)
2+1D QGP Volume in Central d+Au

Volume × Time in QGP [fm² ∆y fm/c]

Center-of-Mass Energy [GeV]

LHC
RHIC
QGP

t = 3 fm/c
4 fm
3 fm

2 fm 2 fm

200 GeV
62 GeV
20 GeV
7.7 GeV

d+Au Beam Energy Scan


Hydro With Pre-Equilibrium

Hydro Without Pre-Equilibrium

$V_2$

20 GeV

39 GeV

62 GeV

200 GeV

$[\text{GeV/c}]$

$[\text{GeV/c}]$

$[\text{GeV/c}]$

$[\text{GeV/c}]$

$[\text{GeV/c}]$

$p_T$ [GeV/c]

$p_T$ [GeV/c]

$0.05$

$0.1$

$0.15$

$0.2$

$0.05$

$0.1$

$0.15$

$0.2$
d+Au Beam Energy Scan


Hydro With Pre-Equilibrium
Hydro Without Pre-Equilibrium
AMPT Parton + Hadron
d+Au Beam Energy Scan


Hydro With Pre-Equilibrium
Hydro Without Pre-Equilibrium
AMPT Parton + Hadron
AMPT Hadron Only

Stay tuned for PHENIX Run16 results!
Small Collision Systems
Jets in d+Au

INITIAL STATE

Geometric Characterization
- Centrality
- $N_{\text{coll}}$
- $N_{\text{part}}$
- Eccentricity

Partonic Structure of the Nucleus
- Cold nuclear matter effects
- Nuclear parton densities

Jet Measurements in d+Au
Minimum Bias Jet $R_{dAu}$

No modification in minimum bias collisions
Central suppression consistent with energy loss models
Centrality-Dependent Jet Modification in d+Au

How can we explain this?
Centrality-Dependent Jet Modification in d+Au


**x-dependent proton size fluctuations?**

Centrality-Dependent Jet Modification in d+Au


See D. Perepelitsa’s Talk Tomorrow!
Flow in small systems?

Geometry engineering provides key tests

Hydrodynamics gives good description of $\nu_n$

Initial geometry drives anisotropy signal
Summary

Flow in small systems?

- Geometry engineering provides key tests

  Hydrodynamics gives good description of $v_n$

  Initial geometry drives anisotropy signal

Jets in d+Au

- Test relation between hard and soft processes

  Intriguing centrality-dependent modification of jet production rates