PHENIX Results On Small Systems

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Small Collision Systems
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

\[
\begin{align*}
\varepsilon_2^{\text{IPGlasma}} & = 0.099 \\
\varepsilon_2^{\text{Glauber}} & = 0.231 \\
\varepsilon_2^{\text{IPGlasma}} & = 0.595 \\
\varepsilon_2^{\text{Glauber}} & = 0.540 \\
\varepsilon_2^{\text{IPGlasma}} & = 0.555 \\
\varepsilon_2^{\text{Glauber}} & = 0.504
\end{align*}
\]

Courtesy of Björn Schenke
Geometry Engineering at RHIC

Structure of the proton is important

Geometry dominated by elliptic/triangular shape.

ONLY AT RHIC

\[ \varepsilon_2^{\text{IPGlasma}} = 0.099 \]
\[ \varepsilon_2^{\text{Glauber}} = 0.231 \]

\[ \varepsilon_2^{\text{IPGlasma}} = 0.595 \]
\[ \varepsilon_2^{\text{Glauber}} = 0.540 \]

\[ \varepsilon_2^{\text{IPGlasma}} = 0.555 \]
\[ \varepsilon_2^{\text{Glauber}} = 0.504 \]
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

$p+p$

Clear near-side ridge

Compare to $p+p$ reference
Long Range Azimuthal Correlations

Central $^3\text{He}+\text{Au}$

Central $p+p$

Central $p+\text{Au}$

- $p+\text{Au} 200\text{GeV} 0 - 5\%$
- $1.0 < p_{T,\text{trig}} < 3.0 \text{ GeV/c}$
- $|\eta_{\text{trig}}| < 0.35$
- $-3.9 < \eta_{\text{asso}} < -3.0$

PHENIX preliminary
Estimating Non-Flow

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

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

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

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**

**Systematics**
- $-3.9 < \eta < -3.1$

**Measurement**
- $-3.0 < \eta < -1.0$

Resolution $\text{Res}(\Psi)$ estimated from correlation of three independent sub-events

\[ v_2 = \frac{\langle \sum \cos 2(\phi - \Psi_2) \rangle}{\text{Res}(\Psi_2)} \]
Asymmetric systematics account for non-flow contribution to $v_2$
Elliptic Flow in all Systems

$V_2$

- $^3$He+Au 200GeV 0-5%
- d+Au 200GeV 0-5%
- p+Au 200GeV 0-5%

$p_T$ [GeV/c]
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

- $p+Au$
- $d+Au$
- $^3He+Au$
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
Hydro + IPGlasma Initial Conditions

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

$\eta/s = 0.12$

Schenke, Venugopalan, Nuclear Physics A 931 (2014) 1039–1044
Hydro + IPGlasma Initial Conditions

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

$\eta/s = 0.18$
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

• Hydro
Going Down in Size and Energy

Pre Equilibrium → QGP Expansion → Hadron Phase
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 y fm/c]

Center-of-Mass Energy [GeV]

How Low Can You Go?

2+1D QGP Volume in Central d+Au

Volume \times Time in QGP [fm^2 \Delta y fm/c] vs. Center-of-Mass Energy [GeV]

LHC
4 fm
3 fm

How Low Can You Go?

2+1D QGP Volume in Central d+Au

Volume x Time in QGP [fm² ∆y fm/c]

Center-of-Mass Energy [GeV]

LHC
RHIC

7.7 GeV 20 GeV 62 GeV 200 GeV

t = 2 fm/c t = 3 fm/c
d+Au Beam Energy Scan


[Graph showing V2 as a function of pT for different beam energies: 20 GeV, 39 GeV, 62 GeV, and 200 GeV. The graph compares superSONIC and SONIC models with and without pre-equilibrium.]
d+Au Beam Energy Scan


Hydro With Pre-Equilibrium

Hydro Without Pre-Equilibrium

AMPT Parton + Hadron
d+Au Beam Energy Scan


Stay tuned for PHENIX Run16 results!
Small Collision Systems

Flow

Jets
Jets in d+Au

INITIAL STATE

Geometric Characterization
- Centrality
- N_{coll}
- N_{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

$PHENIX \ d+Au, \ \sqrt{s_{NN}} = 200 \ \text{GeV}, \ \text{anti-}k_t, \ R=0.3 \ \text{jet}$

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


See D. Perepelitsa’s Talk Tomorrow!

McGlinchey, Nagle, Perepelitsa, arXiv:1603.06607
Summary

Flow in small systems?

Geometry engineering provides key tests

Hydrodynamics gives good description of $v_n$

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
Figure showing the behavior of \( v_2 \) and \( v_3 \) in a PHENIX experiment at 200 GeV, 0-5% Central. The graph compares different models: PHENIX data \( v_2 \), \( v_3 \), SONIC, superSONIC, Glauber+Hydro, IPGlasma+Hydro, and AMPT. The y-axis represents the values of \( v_2 \) and \( v_3 \), while the x-axis shows the transverse momentum \( p_T \) in GeV/c.