PHOENIX

RESULTS AND STATUS

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Introduction to RHIC and PHENIX
Some Recent Results from PHENIX
Status of PHENIX
sPHENIX
RHIC Facility

- Versatile machine Colliding a variety of species over a wide range of energy

RHIC energies, species combinations and luminosities (Run-1 to 16)
PHENIX Detector

- 2 central arms covering 180° total in azimuth and $|\eta| < 0.35$
- 2 muon arms
Evolution of a Heavy Ion Collision

2 classes of observables

- Hard probes (jets, high $p_T$ hadrons, heavy flavor)
- Bulk measurements (flow, multiplicity, temperature)

Incoming Nuclei

Timeline of a Collision

- PCM & clust. hadronization
- NFD
- NFD & hadronic TM
- PCM & hadronic TM
- CYM & LGT
- String & hadronic TM

Illustration: S. Bass

- incoming nuclei
- radius of Au nuclei: $\sim 7\text{fm} = 7 \times 10^{-15} \text{m}$
- time to traverse the nucleus: $7 \times 10^{-15} \text{m} / (3 \times 10^8 \text{m/s}) = 2 \times 10^{-23} \text{s}$

hot matter
hadronic gas

Hadronization
Freeze-out

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Initial overlap asymmetric → pressure gradients
Momentum anisotropy → Fourier decomposition:

\[
\frac{d^2 N}{dp_T d \varphi} \approx 1 + 2 v_1 \cos(d \varphi) + 2 v_2 \cos(2d \varphi) + 2 v_3 \cos(3d \varphi) + 2 v_4 \cos(4d \varphi) + 2 v_5 \cos(5d \varphi) + \ldots
\]
Flow in the QGP

- Mass ordering observed vs $p_T$
  - Expected in hydrodynamics

Flow in the QGP

- Mass ordering observed vs $p_T$
  - Expected in hydrodynamics
- Number of Constituent Quark (NCQ) Scaling
  - Partonic degrees of freedom


Baryons = 3 quarks
Mesons = 2 quarks
Flow in the QGP

Low viscosity $\Rightarrow$ perfect liquid

Very hot: 170 MeV
  $>1$ million times hotter than the core of the sun
  $\sim 15$ billion times hotter than your coffee

- Expected in hydrodynamics
- Number of Constituent Quark (NCQ) Scaling
  - Partonic degrees of freedom
Where are we?

- How hot? How dense do we need?

Mapping the QCD phase diagram
Flow in Small Systems

- Flow observed in small systems consistent with hydro models

- $dAu$ beam energy scan in 2016

- Observation of $v_2$ in central $p+Au$ at RHIC energy
- Hydro-model seems reproduce the $v_2$ in $p+Au$, $d+Au$, and $He+Au$
- Does direct photon flow in small systems?

New!

PHENIX: arXiv:1609.02894

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HARD PROBES

How do high momentum particles interact with the medium?
Energy Loss in the QGP

- Use pp collisions as a baseline for Au+Au
- Suppression of high momentum hadrons ($\pi^0$ & $\eta$)
- Direct photon $R_{AA} \sim 1 \rightarrow$ photons are unmodified
Different Collision Systems

- Central and semi-central \textbf{Cu+Au} yields are suppressed similar to \textbf{Cu+Cu} and \textbf{Au+Au} for similar size collisions.
- Peripheral consistent with 1

**PHENIX for PHENIX at HP2016**

\[ \frac{\pi^0_{AA}}{} \] in \textbf{Cu+Au}, \textbf{Cu+Cu} and \textbf{Au+Au}

- In central and semi-central \textbf{Cu+Au} collisions, \( \frac{\pi^0}{AA} \) yields are suppressed similar to \textbf{Cu+Cu} and \textbf{Au+Au}.
- In peripheral \textbf{Cu+Au} collisions, \( \frac{\pi^0}{AA} \) yields show a hint on enhancement, while suppression in \textbf{Au+Au}, \textbf{Cu+Cu} lies in the middle.

Phys. Rev. Lett. 101, 232301

Physics Rev. Lett. 101, 162301

Seer Sergei Zharko's talk

- Jets suppressed by ~factor of 2 in central \textbf{Cu+Au} collisions.
- Suppression shows no \( p_T \) dependence, a similar trend seen from LHC experiments in Pb+Pb collisions at much higher energies.

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• Despite the challenges of the underlying event and limited detector acceptance, PHENIX has reconstructed jets in Cu+Au collisions
Cu+Au Suppression

\[ \pi^0, \text{Cu+Au} 60-90\%, \sqrt{s_{NN}}=200 \text{ GeV} \]

\[ \pi^0, \text{Cu+Au} 0-10\%, \sqrt{s_{NN}}=200 \text{ GeV} \]

PHENIX preliminary

\[ p_T (\text{GeV}/c) \]

\[ R_{AA} \]

PHENIX preliminary

\[ p_T (\text{GeV}/c) \]

\[ R_{AA} \]

\[ \pi^0 \text{ measurements and reconstructed jet results in Cu+Au show consistent trend.} \]

\[ \text{But where did the energy go?} \]

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Goldem Channel of Energy Loss

- Unmodified direct photon gives initial energy of away-side parton
- Can measure fragmentation functions:

\[ p_T^\gamma \approx p_T^{jet}, \quad z_T = \frac{p_T^h}{p_T^\gamma} \quad \implies \quad D_q(z_T) = \frac{1}{N_{evt}} \frac{dN(z_T)}{dz_T} \]

\[ \xi = \ln(1/z_T) \]

\[ I_{AA} = \frac{Y_{AA}}{Y_{pp}} \sim \frac{D_{AA}(z_T)}{D_{pp}(z_T)} \]

\[ I_{dA} = \frac{Y_{dAu}}{Y_{pp}} \]
Golden Channel of Energy Loss

- $I_{AA}$ shows suppression at low $\xi$ (high hadron $p_T$) and enhancement at high $\xi$ (low hadron $p_T$)

- $I_{dA}$ No significant modification in $dAu$

\[
I_{AA} = \frac{Y_{AA}}{Y_{pp}} \sim \frac{D_{AA}(z_T)}{D_{pp}(z_T)}
\]

\[p_T^\gamma \approx p_T^{\text{jet}} \quad z_T = \frac{p_T^h}{p_T^\gamma} \quad \Rightarrow \quad D_q(z_T) = \frac{1}{N_{evl}} \frac{dN(z_T)}{dz_T}
\]

\[\xi = \ln\left(\frac{1}{z_T}\right)\]
Where does the lost energy go?

- Enhanced low momentum particles for wide angle

**Motivation:** why $\gamma_{\text{direct}} - h$?

QCD Compton Scattering

Direct Photon Processes at LO

Annihilation

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Where does the lost energy go?

- How does the enhancement change with smaller windows

![Diagram](image-url)

Motivation: why $\Upsilon_{\text{direct}-h}$?
Where does the lost energy go?

- The enhanced low momentum production is most significant for wide angles
- Consistent with broadening due to radiative energy loss
Cross over to enhancement

- How does the cross over depend on the photon energy?
- Not at consistent $\xi$
- Consistent with model expectations
- More data from 2014 and 2016
PHENIX in 2016

- Collaboration photo taken in September
- Phenix is currently being disassembled

Last data collected June 2016

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But what about…

- Reconstructing jets opposite a direct photon?
- Fragmentation functions from reconstructed jets?
- Heavy flavor tagged jets?
- A precise measure of the suppression of different upsilon states?

…RHIC/AGS User’s Meeting

Sarah Campbell

Sidebar 2.5: Jetting through the Quark-Gluon Plasma

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sPHENIX

- Jet Structure & Fragmentation
  - Dijets, γ-jet, h-jet, jet-h
- Y suppression
  - for different states
- b-jets:
  - Quark/gluon jet
  - Radiative vs Collisional energy loss

![Heavy ion runs - time evolution of Au+Au](image_url)
Jet Detector at RHIC

- Proposed upgrade
  - High rate: Sampling 50 billion Au+Au events in one year

10^7 jets > 20 GeV
10^6 jets > 30 GeV
80% are dijet events
10^4 direct γ > 20 GeV
Timeline for sPHENIX

- Jan 2022 First data
- Now: Conceptual design stage
  - Prototypes and test beams
Summary

• The QGP is a hot dense liquid
  • Hydrodynamics describes the observed flow
• Evidence of flow in small systems also described by hydrodynamics (QGP droplets?)

• Suppression observed for pions in Cu+Au, Au+Au and Cu+Cu
• Reconstructed jets measured in Cu+Au show similar suppression as pion measurements
• Direct-photon hadron correlations are useful for studying energy loss
  • In central Au+Au: High momentum energy loss is redistributed to low momentum particles produced at large angles
  • No modification observed in dAu

• PHENIX has concluded its data taking phase and continues to publish important results
• sPHENIX is coming to life and will make precise measurements with jets and heavy flavor probes
THANKS!