Recent Highlights at RHIC

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NSAC Meeting
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Heavy Ion Collisions at RHIC

“White Papers” from the four experiments summarizing the first 3 years

- Evidence for the creation of a new state of thermalized matter.
- Highest energy density matter accessible in the Laboratory
- It’s density and enormous interaction cross section not consistent with hadronic degrees of freedom
- Medium exhibits collective expansion with extraordinarily small viscosity-to-entropy ratio
AIP number one physics story of 2005...
The White Papers, Joint publication: Nuclear Physics A, August, 2005

A new view of high-temperature matter:
“Ideal” Hydrodynamics
• Near-zero viscosity
• Very quick thermalization

“Perfect Liquid”

Press Event:
Tampa APS Meeting, April 2005

Strongly-coupled QGP = “sQGP”
New Results from RHIC 2004/2005 runs
Probing a partonic state of dense matter…

How dense?
• 20 GeV $\pi^0$ stopped in nuclear volume: $\varepsilon > 15$ GeV/fm$^3$
• Heavy quarks are quenched: problem for radiative energy loss
• J/$\Psi$ suppression measured: Melting? Regeneration?

How strongly coupled?
• Charm quarks flow!

How hot?
• First measurements of direct (thermal?) photons

How can we see inside?
• “punch through” of quenched jets shows effects of medium
• di-jet tomography emerging as a powerful tool
\( R_{AA} = \text{scaled prod. Rate: (Au-Au/p-p)} \)

"opaque" strongly interacting medium: 20 GeV \( \pi^0 \) stopped

Direct photons not suppressed

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PHENIX Au+Au (central collisions):
- Direct \( \gamma \)
- \( \pi^0 \) Preliminary
- \( \eta \)
- GLV parton energy loss (\( dN^0/dy = 1100 \))

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schematic view of jet production

hadrons

leading particle

leading particle
Charm is quenched in Au-Au collisions!

Heavy quarks suffer a large energy loss: A serious problem for the "standard" scenario of energy loss by gluon radiation.

PHENIX, Quark Matter’05

STAR Preliminary
**J/ψ suppression at RHIC**

A long-proposed “signature” for a deconfined partonic state

- deconfinement $\rightarrow$ screening
- $\rightarrow$ no heavy quark bound states in a QGP

### Preliminary data are consistent with predictions for melting + regeneration at RHIC energy density

**J/ψ** is suppressed beyond the cold nuclear matter effect (d-Au result).

Preliminary data are consistent with predictions for melting + regeneration at RHIC energy density

“Same as SPS”? 
Charm Flows in Au-Au collisions!

Indicates high parton density and strong coupling in the collectively expanding medium

Not a weakly-coupled gas
The Medium Modifies Quenched Jets

The text mentions the following conditions:

- $4.0 < p_T^{\text{trig}} < 6.0$ GeV/c
- $2.0 < p_T^{\text{assoc}} < p_T^{\text{trig}}$ GeV/c
- $0.15 < p_T^{\text{assoc}} < 4.0$ GeV/c

Graphs and plots show distributions of $1/N_{\text{Trigger}} \, dN/d(\Delta \phi)$ as a function of $\Delta \phi$ (radians) for different centrality bins in $d+Au$ and $Au+Au$ collisions, comparing $p+p$ and min-bias conditions. The plots also highlight the differences in $J(\Delta \phi)$ for various centrality cuts.
The Emerging Picture

We are developing powerful tools -- experimental and theoretical -- to explore this new landscape.

Most involve rare processes – Hence the need for improved luminosity, and upgraded detectors.

Why is thermalization so fast?
RHIC Delivered Luminosity

RHIC nucleon-pair luminosity $L_{NN}$ delivered to PHENIX

- Au-Au 100 GeV/n
- Cu-Cu 100 GeV/n
- d-Au 100 GeV/n
- p-p 100 GeV
- Au-Au 65 GeV/n
- Cu-Cu 31.2 GeV/n
- Au-Au 31.2 GeV/n

Nucleon pair luminosity $L_{NN} [pb^{-1}]$

Calendar year

Last update: 7 July 2005
2005 Cu-Cu Run: Tight control over systematics

PHOBOS 62 GeV
- Cu-Cu 3-6%, Npart=96
- Au-Au 35-49%, Npart=98

PHOBOS 100 GeV
- Cu-Cu 3-6%, Npart=100
- Au-Au 35-40%, Npart=99

Crisp studies of baryon/meson enhancement at intermediate values of \( p_T \)
(PHENIX)
RHIC Spin

Run 5 (2005)\( p - p \):
- 9.5 weeks physics at 100 + 100 GeV
- 12 pb\(^{-1}\); 50% polarization
- First test of polarized collisions at 205 + 205 GeV

Run 6 (2006) dedicated spin run
- 20 week physics run of polarized proton collisions
- setup in progress; physics to start next week
- Made possible by $13M contribution from Renaissance Technology Corp.

Gluon polarization measurement: \( \Delta G \)

\[ \begin{align*}
p \ p & \rightarrow \pi + X \\
& \quad \text{Jet(s) + X} \\
& \quad \gamma + \text{jet} + X
\end{align*} \]

Double-spin asymmetry \( A_{LL} \) directly sensitive to gluon contribution

\[ \begin{align*}
\vec{p} + \vec{p} & \rightarrow \gamma (+ \text{jet}) + X \\
\text{Quark - Gluon Compton Scattering} & \\
\vec{p} + \vec{p} & \rightarrow \text{di-jets} + X \\
\text{Quark - Gluon (also Gluon - Gluon) Elastic Scattering}
\end{align*} \]
**RHIC SPIN**

**$A_{LL}$**

- Run 5 (Preliminary)
- GRSV-max
- GRSV-std

Scaling error of 40% is not included.

$p + p \rightarrow \gamma + X$

Curves: NLO pQCD calculations by Vogelsang et al.

**STAR**

$\bar{p} + \bar{p} \rightarrow \text{jet} + X$ at $\sqrt{s}=200$ GeV

- $-1 < \eta^{\text{jet}} < 1$

Run 6 Projections $L=10$ pb$^{-1}$ $P=0.50$
The RHIC Spin Research Plan

- Complete $\Delta G$ measurements
- Transverse Spin measurements

At 500 Gev: Parity violating W production

Data collection goals from the RHIC Spin Plan, And Collider projections.
RHIC Science Outlook

- QCD at high temperature and density: QGP ... sQGP
- QCD at high energy and low x: Physics of strong color fields
- QCD and the structure of hadrons: What is the origin of nucleon spin?

A Long Term Strategic View

~2012

• RHIC II construction
• Luminosity upgrades
• Forward upgrades
• eRHIC
• E beam + new detector

2006

• 5-10 GeV static electron ring
• recirculating linac injector

Mid Term Plan
The Mid-Term Strategy: 2006 - 2011

Phased implementation of key upgrades for PHENIX and STAR detectors

Study the new form of matter with resolving power afforded by hard probes

Annual data runs during this period will exploit these upgrades for critical advances in the Heavy Ion and Spin physics programs—Along with continued improvements in machine performance

With the help of funding and collaborative resources outside of DOE, this strategy is realized with a sequence of MIE detector upgrade projects over ~6 years.

Two large detectors well equipped for RHIC II physics

RHIC II luminosity upgrade (electron-cooling of ion beams) proceeds along technically-driven schedule
Major Physics Measurements
Required Upgrades

Heavy Ion:
- e-pair mass spectrum
  - “Hadron Blind” Dalitz pair rejection PM: 2010
- Open charm measurements in AA
  - Precision vertex detection
- Charmonium Spectroscopy PM: 2010
  - High luminosity; precision vertex, particle ID
- Jet Tomography
  - High luminosity; increased acceptance; particle ID
- Gluon shadowing; low-x in d-Au
  - Particle detection at forward rapidity PM: 2012

Spin:
- Complete initial $\Delta G/G$ measurement
  - No upgrades needed PM: 2008
- Transverse spin measurement
  - Forward particle measurement
- $W$ measurements at 500 GeV PM: 2013
  - Forward tracking/triggering in PHENIX and STAR

*DOE performance milestones set by NSAC
What are the phases of QCD matter?

What is the wave function of the proton?

What is the wave function of a heavy nucleus?

What is the nature of non-equilibrium processes in a fundamental theory?

**Fundamental Questions for the coming decades**

**QCD diagrams, late XX century**

**QCD diagrams, early XXI century**

**RHIC...RHIC II...LHC HI... eRHIC**