Perfect Fluid Created at RHIC

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PHY 599

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Outline

- The motivation

  create and study the new state of matter,

  QGP under high temperature

- The expectation

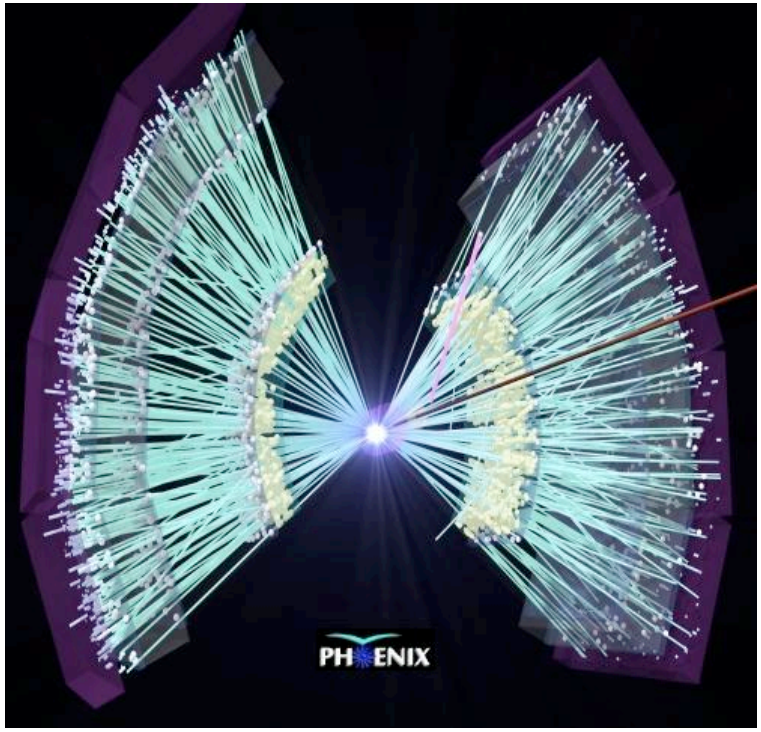
  QGP…weakly interacting gas

- The discovery

  QGP…strongly interacting fluid

- Conclusion

Relativistic Collisions of Heavy Nuclei



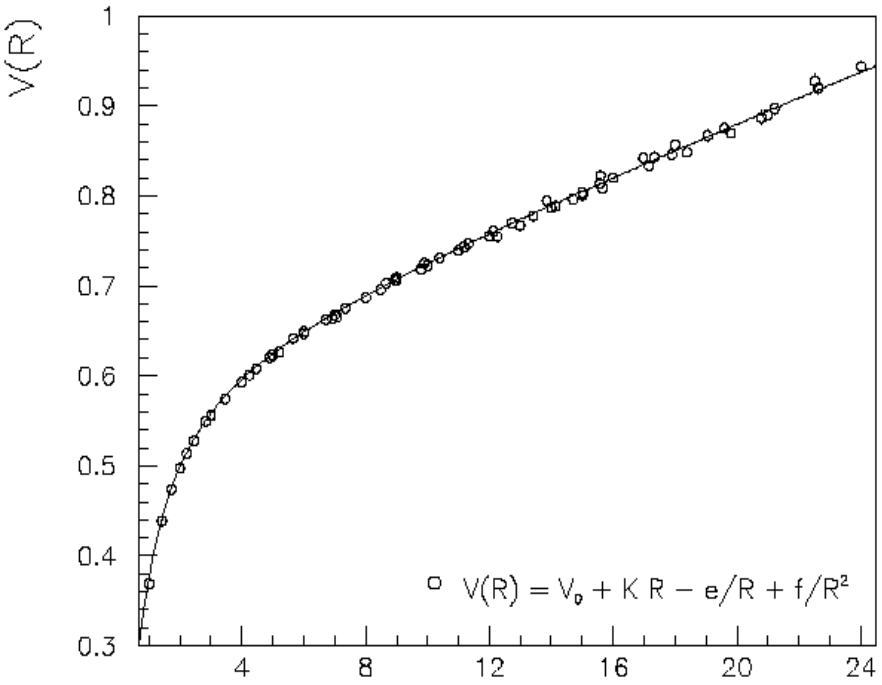
Au-Au, p-p, d-Au collisions

$T > 10^{12}$ K

last seen ~ 1 microsecond after the Big Bang.

High temperature nuclear (QCD) matter

- Hot: critical temperature
  ~ 170MeV ~ 10^12 K
- Dense
- Asymptotic Freedom



Prediction

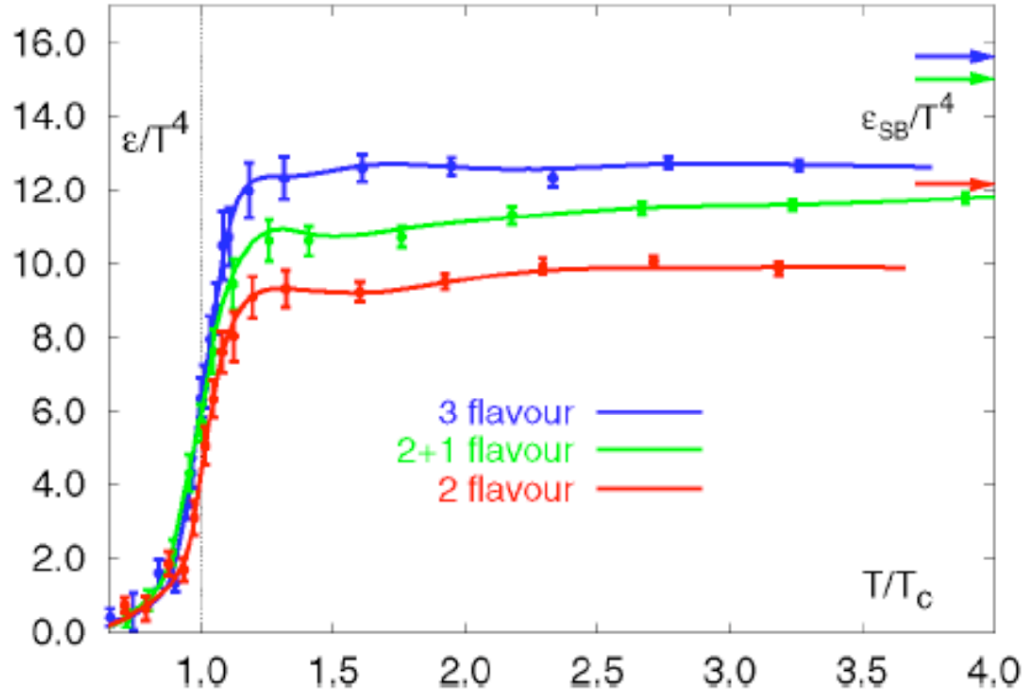


Fig. 1. Lattice QCD results [11] for the energy density/T^4 as a function of the temperature scaled by the critical temperature T_C. Note the arrows on the right side indicating the values for the Stefan–Boltzmann limit.

Quark Gluon Plasma

Plasma

ionized gas
charge neutral
electromagnetic interactions

Quark Gluon Plasma

weakly coupled gas

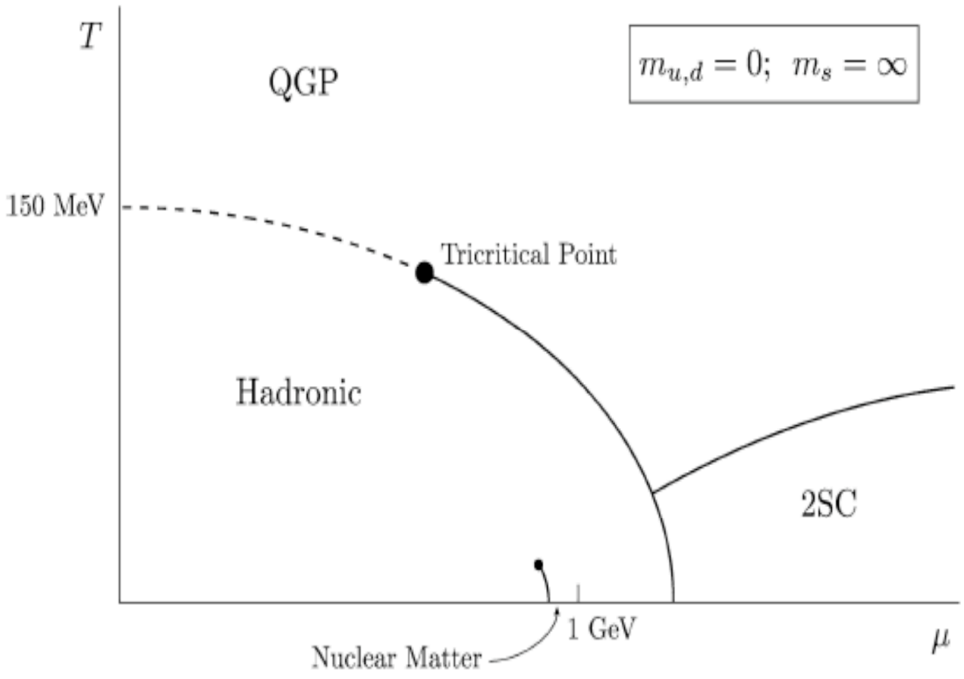
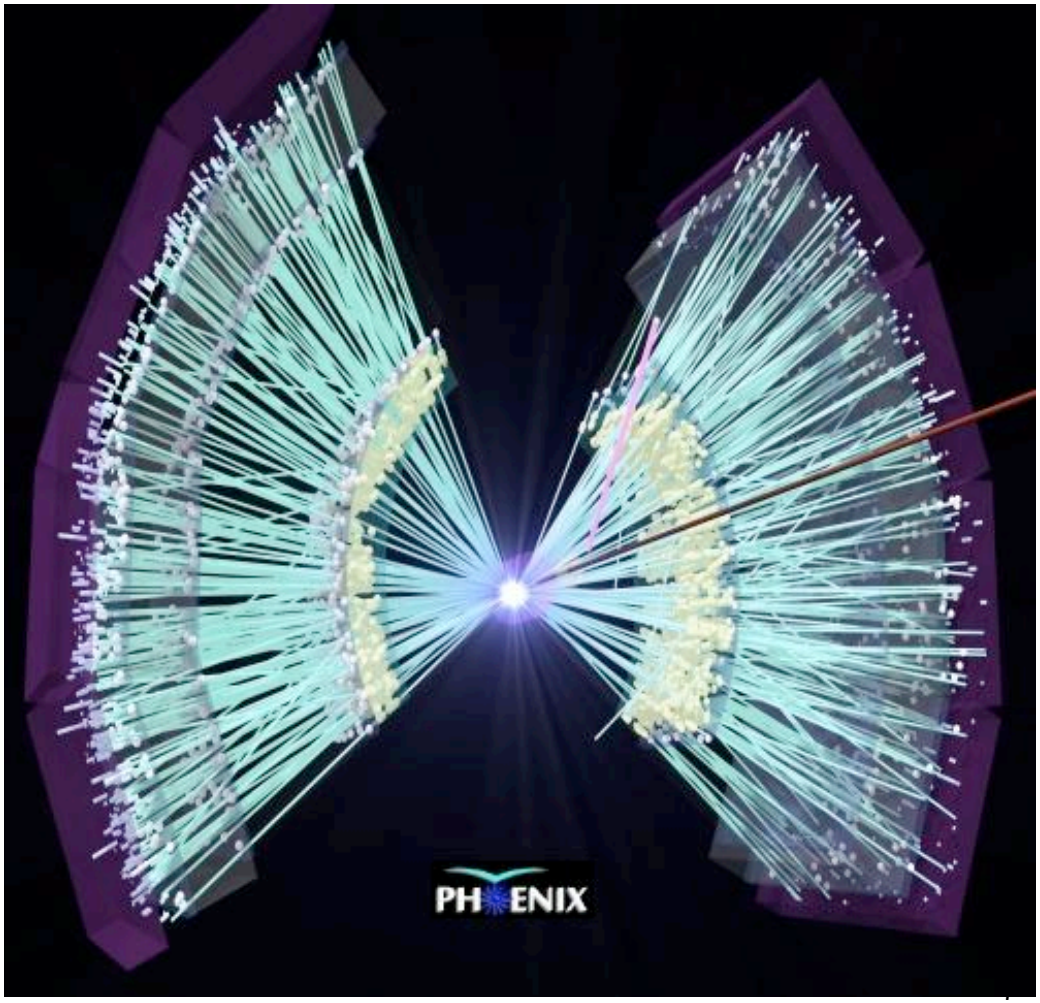


Fig. 2. Theoretical phase diagram of nuclear matter for two massless quarks as a function of temperature T and baryon chemical potential μ [12].

Experiment at RHIC …QGP is liquid

- $T > 10^{12}$ K
- Thermalization time 10^{-24} sec



Fluid: the laws of fluid dynamics

- Shear viscosity: η

$$\frac{F}{A} = \eta \nabla_y v_x .$$

Rate of momentum transport

To measure it, use viscometer

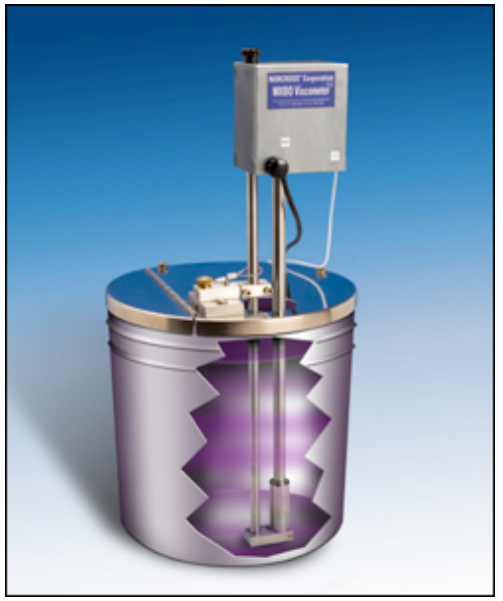
- Example: water

conserved quantities

mass

energy

momentum.



No viscometer….

- measure…

  The distribution of charged particles produced in the collisions as a function of azimuthal angle φ

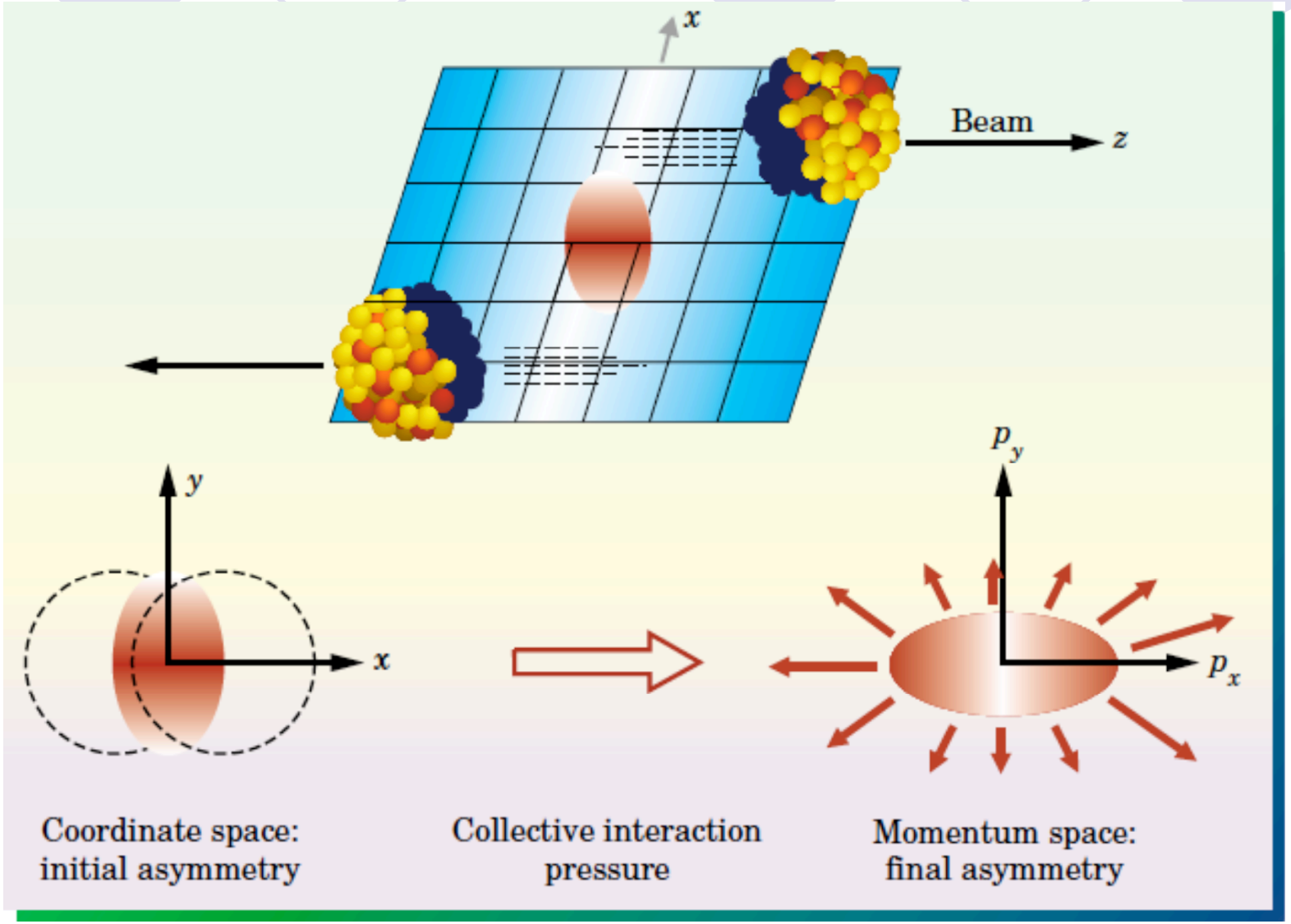
  p_t transverse momentum

  y rapidity

→ Hydrodynamic calculation

QGP is fluid
- Flow
- Viscosity

Elliptic flow



Elliptic flow: Fourier analysis

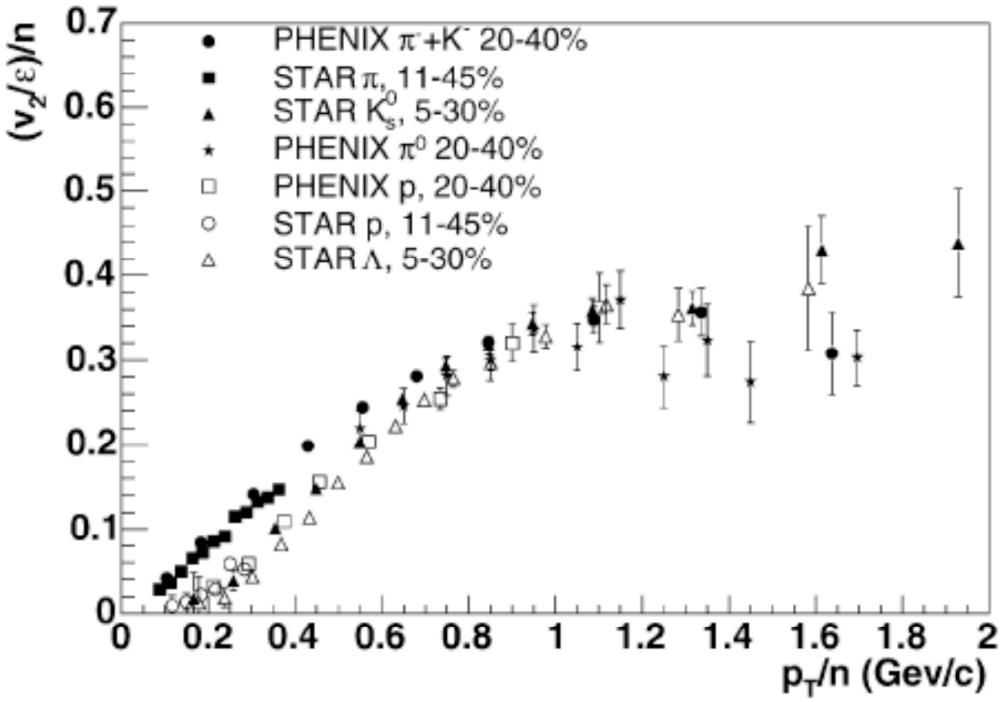
Elliptic flow pattern… V_2

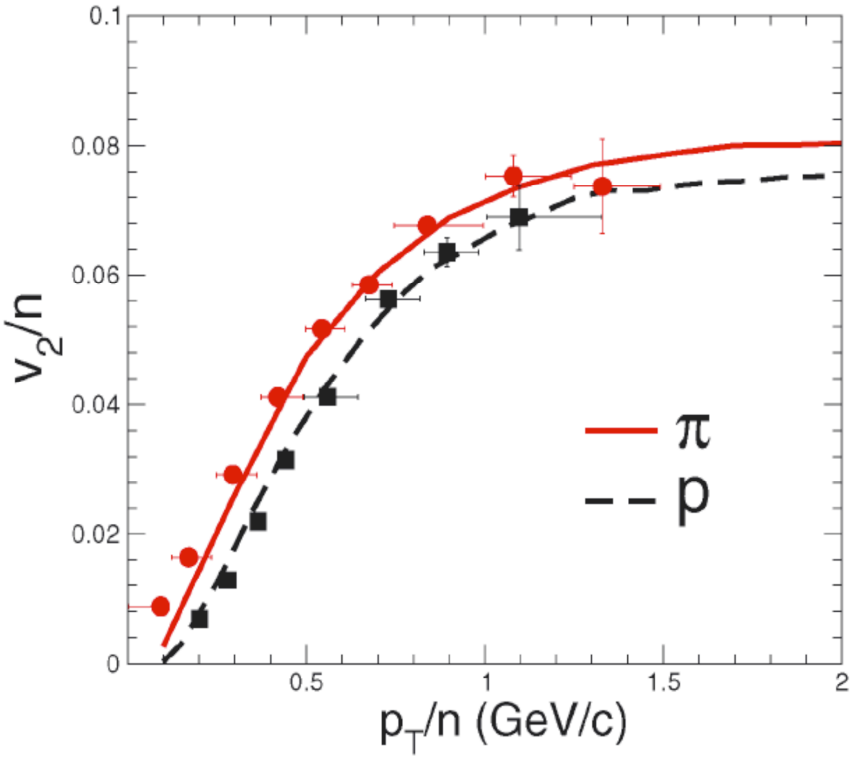
$$\frac{dN}{d\phi} = \frac{v_0}{2\pi} + \frac{v_2}{\pi}\cos(2\phi) + \frac{v_4}{\pi}\cos(4\phi) + \cdots.$$

Harmonics, each v_i is a function of

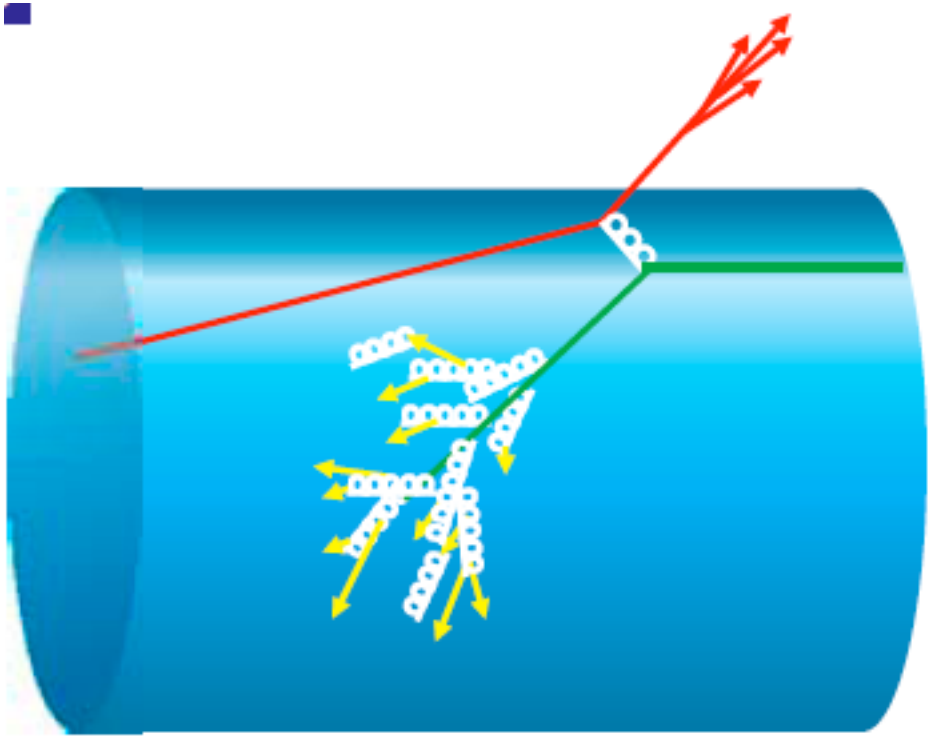
the impact parameter
rapidity
transverse momentum
particle type

Experimental result





Jet quenching (hard probes)



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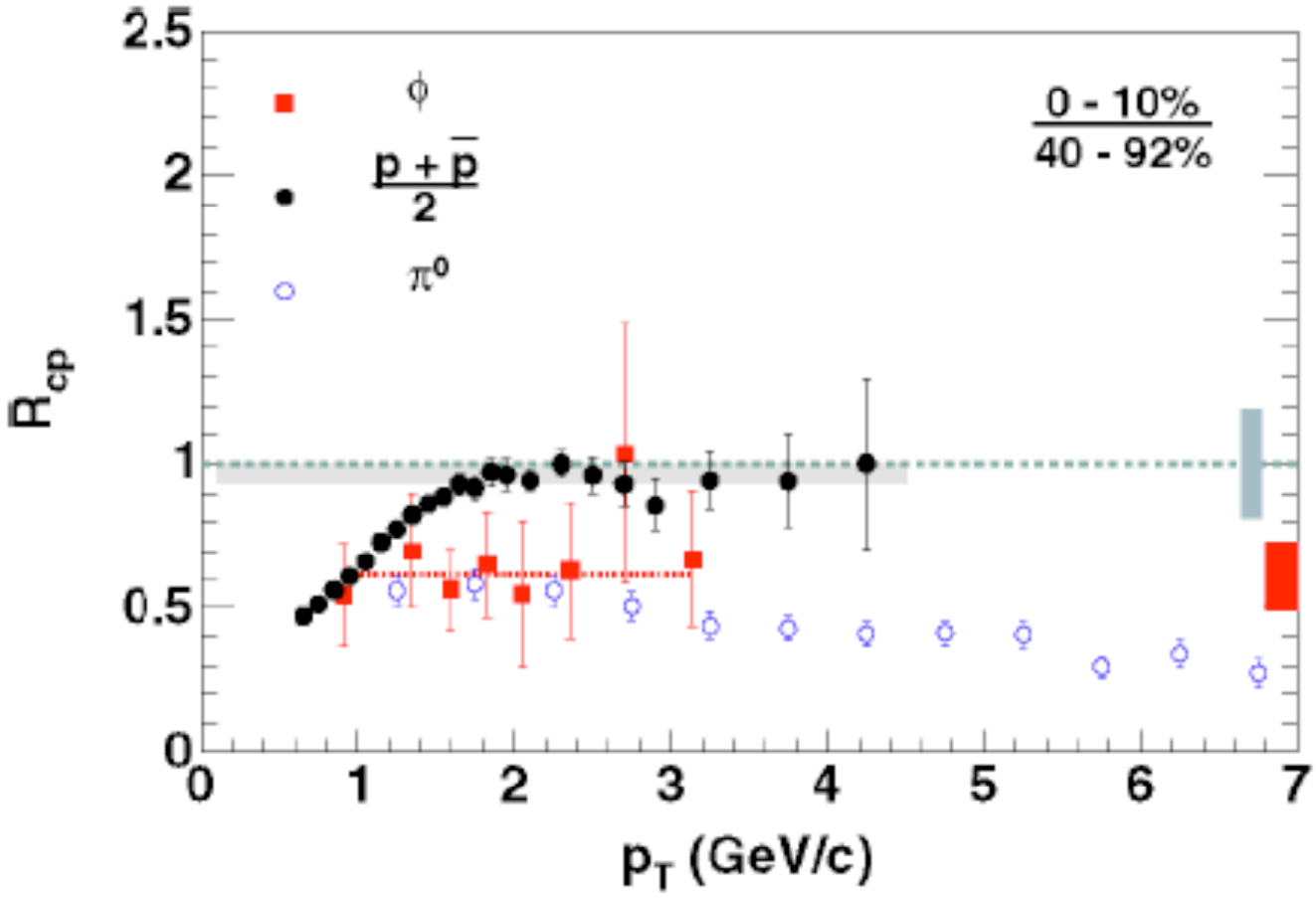
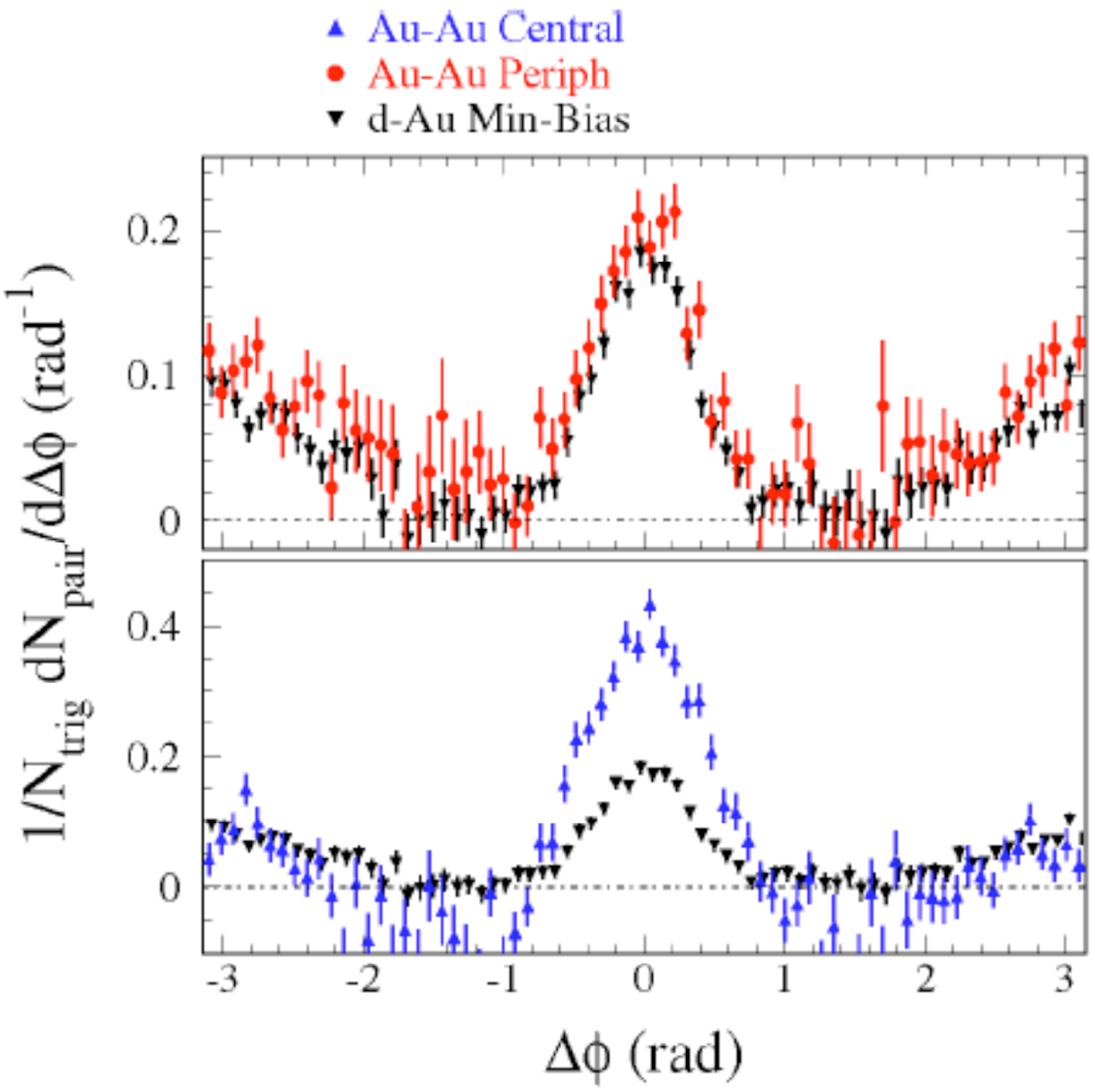



Au-Au Central
Au-Au Periph
d-Au Min-Bias
$1/N_{trig}\ dN_{pair}/d\Delta\phi\ (rad^{-1})$
0.2
0.1
0
0.4
0.2
0
-3
-2
-1
0
1
2
3
$\Delta\phi$ (rad)

Viscosity

- Viscosity was extracted from experimental data

  relativistic fluiddynamics

$$\frac{\eta}{s} \geqslant \frac{\hbar}{4\pi k_{\mathrm{B}}},$$

  S(entropy)

  very small value! ⟶ Perfect Fluid

Conclusion

- QGP

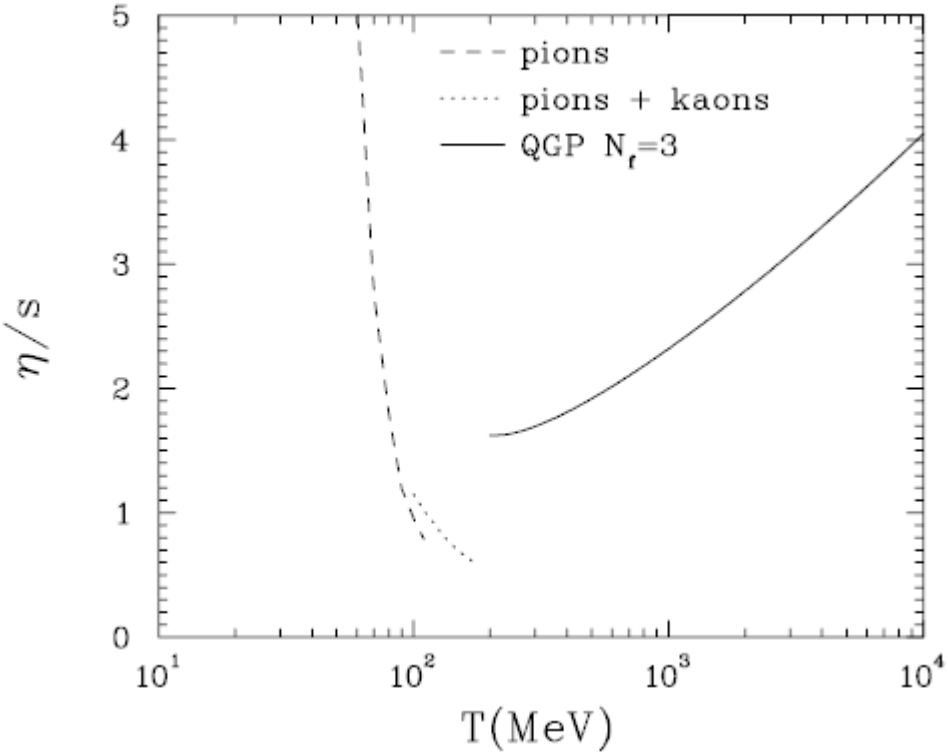
  Strongly interacting fluid

Questions

Minimum value of viscosity

Screening length

Mechanism of rapid equilibriun achievement



Reference

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- Shuryak E, “What RHIC experiment and theory tell us about the properties of quark-gluon plasma?”, Nuclear Physics A 750 (2005) 64–83
- T Schafer and Teaney, “Nealy perfect fluidity: from cold atomic gases to hot quark gluon plasmas”; Rep. Prog. Phys. 72(2009)
- Jacek, “The Hottest Science Experiment on the Planet: Exploring the Strong Interaction at RHIC”, URL:http://insti.physics.sunysb.edu/itp/conf/simonswork8/

- Experiment:

RHIC, “Nuclear Physics A Volume 757, Issues 1-2 , 8 August 2005, Pages 184-283” URL: http://www.phenix.bnl.gov/WWW/info/comment/