High-Energy Nuclear Collisions

I. STAR experiment at RHIC
II. Properties of medium and the QCD phase structure
III. The future of RHIC

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Part I: Introduction
Part II: STAR Experiment at RHIC
Part III: Properties of Medium and the QCD Phase Structure
Part IV: The Future of RHIC
The QCD Phase Diagram and High-Energy Nuclear Collisions

1. $T_{\text{init}}, T_C$  
   RHIC, LHC

2. $T_E$  
   RHIC, FAIR

3. Phase boundary  
   RHIC, FAIR, NICA

Temperature

Baryon Chemical Potential

Early Universe

1

2

3

$T_E$ Critical Point?

hadron gas

nuclei

quark-gluon plasma

CSC
Timeline of QCD and Heavy Ion Facilities

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Nu Xu, September 2009

Legend:
- Spin
- R&D
- Heavy Ion
- Future programs
Fundamental Scientific Issues

1) How the thermalization reached in sQGP?
   - parton energy loss, heavy quarkonia, di-leptons

2) What is the QCD phase structure?
   - QCD phase boundary, critical point, glueball

3) What is the beginning\(^{(3)}\) of the beginning\(^{(1)}\) ?
   - initial wave-function of the cold nucleus, proton helicity structure

STAR Decadal Plan Discussions: Sept. 10\(^{th}\) collaboration meeting
EIC at RHIC
eRHIC Design 2020

eRHIC-I $\rightarrow$ eRHIC: energy of electron beam is increased from 5 GeV to 30 GeV by building up the linacs

RHIC: 325 GeV p or 130 GeV/u Au with DX magnets removed
EIC: $\vec{e} + \vec{N} \Rightarrow$ Nucleon Structure

- DIS, $\gamma$-gluon fusion $\Rightarrow \Delta G (x > \text{few} \times 10^{-4})$
- Bjorken sum rule test to $\leq \pm 2\%$
- SIDIS for low-$x$ sea-quark polarization and transverse spin studies

More luminosity-hungry:
- Polarized DVCS, exclusive reactions + LQCD $\Rightarrow$ GPD’s $\Rightarrow$ map low-$x$ transverse position-dep. PDF’s
- High-$Q^2$ $\vec{e}p,d$ parity viol’n $\Rightarrow$ weak coupling running below Z-pole
Nucleon structure functions: gluons

i) Gluon density increases with $\frac{1}{x} = \frac{2 \times p}{\sqrt{S_{NN}}}$

ii) At fixed $x$, gluon density increases with momentum transfer $Q^2$

At small $x$, gluon number saturates. A unique initial state.
Connections: A-A to p-A to e-A

- e-A: Precise understanding of A in A+A
  - Initial state: saturation and more generally nuclear PDF’s
  - Energy loss in cold nuclear matter
- Precise control of kinematics, map independently x and Q^2
- Factorization: initial probe via QED rather than QCD

![Graph showing Q^2 and x relationships for different energies and nuclei](image)

STAR FMS here
CBM at FAIR
QCD-Phase Diagram: CBM
HI beam 2 to 45 AGeV
Science at FAIR

- Atomic Physics Plasma & Applied physics
- Nuclear & Quark Matter
- Exotic Nuclei & Nuclear Astrophysics
- Hadron Structure & Dynamics

- APPA
- CBM
- NuSTAR
- PANDA

- Fundamental Science
- Advanced Technology
- Cutting-edge IT
CBM at FAiR (2018 date taking starts)

- RICH
- TRD
- ECAL
- TOF
- μ-ID
- STS

- di-electron Spectrometer
- di-muon Spectrometer
1) How the thermalization reached in sQGP?
   - parton energy loss, heavy quarkonia, di-leptons

2) What is the QCD phase structure?
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Quantum Chromodynamics

1) Quantum Chromodynamics (QCD) is the established theory of strongly interacting matter.

2) Gluons hold quarks together to form hadrons:

3) Gluons and quarks, or partons, typically exist in a color singlet state: confinement.
Selected QCD Results

\[ \alpha_s(Q^2) = \frac{12\pi}{(33 - n_f)\ln(Q^2/\Lambda^2)} \]

\(\alpha_s\) diverges as \(Q^2 \rightarrow \) small (long distance)  
\(\Rightarrow\) no free quarks
QCD Phase Diagram 1983

1983 US Long Range Plan - by Gordon Baym

$T_c \sim 200 \text{ MeV}$

$(1, 2, 5-10) \rho_0$
- QCD is a fundamental force
- Evolution of the universe

The study of the structure of matter with QCD degrees of freedom has just started. Many decades of the efforts are ahead of us.

You are most welcome to join us!
Thank you for your attention!

谢谢！