Hot and Cold QCD Matter





ENERGY

BROOKHAVEN



Hot QCD Matter



Dunlop Hot and Cold QCD

RHIC: A Flexible Machine



To do condensed matter at the femto-scale, need to tune matter properties over a wide range

The Most Vortical Fluid



STAR: Lambda spin is polarized with respect to reaction plane Apparently strongest at lowest energies

- Consistent with vorticity $(9 \pm 1) \times 10^{21} s^{-1}$, far greater than previously observed in any system
- Potential: measurement of late-time magnetic field

8/3/2017

Everything Flows: Heavy Quarks



Technology: High precision low-mass Monolithic Active Pixels >10-year development: First use in a collider experiment Next generation currently being built, at larger scale, for ALICE ITS Charm (m=~5-10*T) flows just as strongly as lighter quarks

Everything Flows: Small Systems



QGP Signatures even in Proton+Proton

ALICE: Nature Physics 13, 535-539 (2017)



Strangeness enhancement (or absence of suppression):

- Long-standing signature of QGP formation
- Observed in high multiplicity p+p collisions at the LHC
- Smoothly interpolates to Pb+Pb and matches in magnitude

Simplest explanation: QGP created Couples with other observations, such as flow signatures in high multiplicity p+p

Observing Topological Charge Transitions

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To observe in the lab - add massless fermions

- apply a magnetic field

Maria

The Chiral Magnetic Effect

The chiral anomaly of QCD creates differences in the number of left and
right handed quarks.right handed quarks.a similar mechanism in electroweak theory is likely responsible for
the matter/antimatter asymmetry of our universe



An excess of right or left handed quarks should lead to a current flow along the magnetic field

Resolving the Question Definitively with Isobars

Measurements consistent with CME, but potential backgrounds Resolve question by changing magnetic field, with all else constant



CME Task Force: V. Skokov, P. Sorensen, V. Koch, S. Schlichting, J. Thomas, S. Voloshin, G. Wang, H.-U. Yee, arXiv:1608.00982 Isobar collisions in 2018 can tell us what percent of the charge separation is due to CME to within +/- 6% of the current signal

Hints of Critical Behavior



Tantalizing hint, but not enoughdprecision proximity of the freezeout curve Machine and detector upgraides: Beam Energies Scale-maximum to recover energies (reversional encercy) an H = const curve is a universalCovered both worldwide and by fixed target in STAR Eq. (10).

Enabling Technology for BES-II





Enhanced detector coverage

63.9 m to IP2



Beam cooling for increased luminosity



Jet Probes of QCD Structure

Parton virtuality evolves quickly and is sensitive to the medium at the scale it probes





Unique critical microscope resolution range at RHIC

Kinematic overlap between RHIC and LHC provides complementarity



Enabling Technology for Jet Probes: sPHENIX

SC BaBar Solenoid 1.5 T

Coverage $|\eta| \le 1.1$

High Precision Tracking

Projective Electromagnetic Calorimeter

Hadronic Calorimeter



Capable of sampling 0.6 trillion Au+Au interactions in one year optimizing the use of RHIC (~50× design) luminosity

Future RHIC Runs and Upgrades



Upgrades to Machine and Detectors to greatly increase capabilities Well matched to world program:

Crucial to change matter conditions over widest possible range

Cold QCD Matter







12 GeV Scientific Capabilities

12 GeV Total Project Cost = \$338MEstimate to Complete~ \$1M

Hall D – exploring origin of confinement by studying exotic mesons





Hall B – understanding nucleon structure via generalized parton distributions and transverse momentum distributions

Hall C – precision determination of valence quark properties in nucleons and nuclei



Hall A – short range correlations, form factors, hyper-nuclear physics, future new experiments (e.g., SoLID and MOLLER)



1st Results from JLAB 12 GeV



The new GlueX results (PRC 95 (2017) 042201) show:

- The reaction mechanism for neutral pions is dominated by pure vector coupling.
 - The first data for beam asymmetry for η production >3 GeV.
 - The GlueX experiment in Hall D can produce timely results.

Next: $\gamma p \rightarrow p J/\Psi$

- J/Ψ photoproduction at threshold
- Gives insight on J/Ψ production mechanism (2-gluon vs 3-gluon)
 - Can also point to nature of charmed LHCb pentaquark



The overall normalization of the GlueX data will shift the black points up or down, but the size of the errors is preserved on the log scale.

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EMC Effect in very light nuclei



Partonic Dynamics and N-N Correlations



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2+1 dimensional Imaging of Quarks & Gluons



Tomography in the Valence Region: ⁴He



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Beyond Longitudinal: RHIC Spin

Phys. Rev. Lett. 116 (2016) 132301



From QCD color factors, unique prediction:

Sign change from DIS to p+p of a specific TMD: Sivers "Universality" test vs. future Electron-Ion Collider program 2017 Run (just completed) will test this prediction with precision +Evolution scheme via comparison to Drell-Yan ^{8/3/2017} Dunlop Hot and Cold QCD

FUTURE: ELECTRON-ION COLLIDER



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QCD Landscape Explored by EIC



Summary



Backup

Proton Momenta in the Nucleus



Projected measurements @ 12 GeV of ²H(e,e'p) cross section mapping high proton momenta induced by short-range repulsive NN core $^{48}Ca \rightarrow ^{40}Ca$ (adding 8 neutron to a f 7/2 subshell) 40% more neutrons

Map ratio of ⁴⁸Ca(e,e'p) and ⁴⁰Ca(e,e'p) cross sections at high proton momenta



Uniqueness of EIC among all DIS Facilities

