Overview of RHIC Performance & Plans

I. Recent RHIC Performance
II. FY08 Research Highlights
III. Long-Term RHIC View
   A. 5-year strategic run plan
   B. Possible upgrades for >2015
   C. Progress toward EIC
IV. Responses to 2007 S&T Recommendations
V. Issues for This Review
Recent Personnel Changes

**At BNL:**
- **Sept. ’07:** Doon Gibbs, new BNL Deputy Dir. for S&T
- Steve Vigdor, new ALD for NPP
- Tom Ludlam, new Physics Chair
- Ed O’Brien, new Asst. to Physics Chair for NP
- **Dec. ’07:** Michael Ernst takes over as interim RCF liaison to RHIC, in addition to his leading RA(tlas)CF
- **Feb. ’08:** Dave Morrison takes over as BNL PHENIX Group Leader
- **Summer ’08:** Gerry Bunce retiring, search for replacement as Spin Group Leader under way

**Outside BNL:**
- **Nov. ’07:** D. Kovar → Acting AD for DOE OHEP
  - J. Simon-Gillo → Acting AD for DOE ONP
- **March ’08:** Nu Xu (LBNL) takes over as STAR Spokesperson
FY08 Major RHIC Events

- Nov. ’07: On-time start to RHIC Run 8 despite CR, thanks to carry-forward funds from FY07
- Dec. ’07: RHIC-II project → stochastic cooling upgrade plan, funded by R&D and AIP ⇒ RHIC-II science 5 years earlier at order of magnitude less cost than in Nuclear Physics LRP
- Jan. ’08: Omnibus bill funding shortfall requires reduction from 30 to 19 cryoweeks in Run 8; switch from highly successful d+Au to drastically shortened p+p run, emphasizing reference data for STAR FMS d+Au measurements (CGC test)
- March ’08: Successful test run of Au+Au at $\sqrt{s_{NN}} = 9.2$ GeV in preparation for critical point search
- April ’08: Launch space expansion of RHIC-ATLAS Computing Facility, funded by BNL GPP & DOE OHEP
- June ’08: PHENIX & STAR White Papers each surpass 500 citations (‘renowned’, RHIC ⇒ 29/50 most cited nuclex papers); NYPA power contract extension for 1 year to June 30, 2009
- Detector upgrade progress: good Run 8 performance of STAR FMS + 1st DAQ1000 sector + 1st 5 TOF trays; PHENIX FVTX construction start; science reviews for PHENIX NCC, STAR HFT
- New physics results: Following slides, plus Jacak, Xu, Bunce talks
Improved Collision Luminosity 2006-8

- Delivered luminosity each year has come close to maximum projected
- Full energy Au+Au in 2007 already exceeded RHIC design goal luminosity
- Another factor ~3 over 2006 L needed to reach enhanced pp design goal
- d+Au completed in 2008 ⇒ x 10 over previous ∫L dt; short p+p run ⇒ small improvement over 2006 luminosity
Improving Proton Polarization

Significant learning curve with unique & complex polarization-preserving equipment in AGS & RHIC

- Absolute Polarimeter (H$^+$ jet)
- RHIC pC Polarimeters
- BRAHMS
- PHENIX
- AGS Booster
- Spin Rotators (longitudinal polarization)
- Solenoid Partial Siberian Snake
- Siberian Snakes
- PHOBOS
- STAR
- POL. H- Source
- LINAC
- Booster
- AGS
- AGS Internal Polarimeter
- AGS pC Polarimeters
- Strong Helical AGS Snake
- Spin flipper
- Spin Rotators (longitudinal polarization)
- Solenoid Partial Siberian Snake
- Siberian Snakes
- RHIC pC Polarimeters

> 60% beam polarization achieved reliably in 2006, compared to 70% goal

> Some fallback in 2008 due to shortened run focused on unpolarized reference data

> Absolute calibration of beam polarization to better than design goal accuracy achieved

> Polarization survival to 250 GeV maximum energy demonstrated
Recent RHIC Research Highlights: Progress in Meeting Fundamental Experimental Challenges

How to pump/probe partonic matter in $10^{-23}$ s?

I. How does the perfect liquid respond collectively to the stimulus of energetic parton passage?

Soft-hard hadron correlations reveal near-side “ridge”: particles focused azimuthally around emerging jet, but spread along directions of emerging remnant nuclei

B. Mohanty for STAR, QM2008

See D. Kharzeev talk 07/08 for one possible explanation of ridge

3-hadron correlations confirm away-side conical emission, reminiscent of Mach cone, first revealed in 2-hadron data:

PHENIX – PRC 77, 011901 (2008)

STAR – arXiv:0805.0622
II. How well do we understand parton energy loss in perfect liquid?


- STAR Au+Au 0-5%
- PHENIX Au+Au 0-10%

Non-photonic electrons at high $p_T$ mainly from c,b decays

$\sim$equal opacity for all high-$p_T$ hadrons in central Au+Au suggests similar E loss for light quarks, heavy quarks and gluons, in marked contrast to pQCD predictions! Need to rethink basic mechanisms of quark/gluon interactions in dense colored matter?
**Recent RHIC Research Highlights III: Can We Quantify Viscosity of the “Perfect” Liquid?**

Elliptic flow of hadrons @ RHIC demands shear viscosity/entropy density not much beyond conjectured quantum limit of $1/4\pi$ (green curves), with sensitivity also to model of initial-state fluctuations and other remaining theoretical ambiguities.
Recent RHIC Research Highlights IV: Signatures for Transformation of the Vacuum?

The nature of the QCD vacuum itself can be altered at high temp. Restoration of chiral symmetry -- spontaneously broken at low temp. -- is predicted.

Does low-mass (low-$p_T$) dilepton surplus seen by PHENIX (and at SPS) signal chiral restoration via modified $\rho$ - response?

CP-symmetry, conserved at low temperature, may be spontaneously broken at high temp. Are there correlated CP-even signals for CP violation that changes sign from event to event? STAR sees EDM-like charge correlations $\perp$ reaction plane, but more mundane interpretations are not ruled out.
Recent RHIC Research Highlights V: Can We Determine the System’s Early Temperature?

- Observe excess $e^+e^-$ pairs at low invariant mass (< 300 MeV) and moderate $p_T$ (1-5 GeV) in Au+Au vis-à-vis p+p.
- Interpret excess as conversion of direct thermal $\gamma^* \Rightarrow$ consistency with hydrodynamic calcs. where temp. ~0.5 fm/c after collision is ~2x LQCD transition temperature.
Recent RHIC Research Highlights VI: Can $\bar{p}$-$p$ Collisions Compete with DIS to Probe Nucleon Spin?

- 1st NLO pQCD analysis incorporating RHIC spin inclusive jet and $\pi^0 A_{LL}$ (2006) data (arXiv:0804.0422) by de Florian, Sassot, Stratmann & Vogelsang

- DIS and RHIC spin impose comparable constraints to date on shape & magnitude of gluon polarization vs. $x$; RHIC spin data should dominate after next long 200 GeV $p+p$ run
Extending QCD Theory

RHIC results are stimulating, testing, exploiting important extensions of theoretical approaches to previously intractable QCD regimes:

1) **Approximating solution to Lattice QCD at non-zero net quark density ($\mu_B \neq 0$)**

2) **AdS/CFT to describe the very strong coupling limit (“channeling Maldacena”)**

3) **Color Glass Condensate approach to an effective theory for the highly non-linear regime of high gluon density, but weak coupling (“seeing the forest through the trees”)**

4) **Moving toward a unified perturbative treatment of transverse spin phenomena, incorporating transverse-momentum-dependent parton distributions**

**BNL theory groups have played leading roles in (1), (3) and (4).**
Take-Away Message #1

- Despite three successive runs shortened by federal budget problems, RHIC continues to make important progress toward fulfilling its scientific missions.

- However, repeated postponements associated with late budget action disrupt sensible planning, slow the science output and have a serious negative cumulative effect on user interest, patience and morale. Foreign investors in RHIC are particularly dismayed.
A Long Term (Evolving) Strategic View for RHIC

RHIC HI starts
Luminosity upgrade:
Further luminosity upgrades (pp, low-E)
RHIC-II science by-passing RHIC-II project
Opportunity for upgrade or 1st EIC stage

EIC = Electron-Ion Collider; eRHIC = BNL realization by adding e beam to RHIC

Legend:
R&D
Construction
Multiple small projects
CD0: DOE Critical Decision, mission need

RHIC, RHIC-II, LHC-HI and EIC science share a common theme...
RHIC Science: Condensed Matter Physics with a Force of a Different Color

What are the unique quantum many-body manifestations of a non-Abelian gauge theory and self-interacting force carriers? Are there lessons for other fundamental theories, that are more difficult to subject to laboratory investigation? How do we pump/probe fleeting partonic matter in $10^{-23}$ s?

Apply to
new matter: quantify properties of “near-perfect liquid” seen @ RHIC
old matter: determine partonic decomposition of p spin @ RHIC & eRHIC
hot matter: search for critical point in QCD phase diagram in RHIC E-scan
cold matter: expose & map intense force field (Color Glass Condensate) at heart of all ordinary matter, using eRHIC
Making It All Happen, in 3 Acts...

I. Push time scale for RHIC-II science program earlier than Long Range Plan (~2017 start)
   -- with stochastic cooling, luminosity upgrade by 2012; detector upgrades ongoing, all completed by ~2014

II. Formulate upgrade plan for ~2016-2021 period, to be carried out in parallel with RHIC-II science
    -- e.g., 1st stage toward EIC; or AGS precision experiments

III. Make EIC science case and technical feasibility more compelling by next LRP (~2012-13?), for implementation in early 2020’s
    -- deepen (more transformational, less incremental) and broaden (add electroweak symmetry tests) science case; grow e-A experimental community; continue aggressive R&D program; consider staging strategies; work with JLab to move toward optimized design.
Stochastic Cooling Facilitates RHIC-II Science Without RHIC-II Project

- By 2012: 1 transverse cooling system per ring ⇒ rely on coupling between radial and vertical betatron tunes to transfer cooling to 2nd transverse plane

- Anticipate gain factor ~ 6-8 in \( \int L \, dt \) within \(|z| < 20\) cm, vs. no cooling

56 MHz SRF reduces leakage to neighboring rf beam buckets

Combine 56 with present 197 MHz RF ⇒ tighten vertex distrib’n, as needed with short micro-vertex upgrades.

See T. Roser, M. Brennan talks for details

Calculation by M. Blaskiewicz.
Turning RHIC Into a Hotbed of Beam Cooling

Coherent Electron Cooling of high-energy hadron beams: high-gain FEL based on high-brightness ERL (V. Litvinenko & Y. Derbenev) ⇒ potential to boost LHC and EIC luminosities.

Developing Energy Recovery Linac (ERL) technology for high-current, medium-E e beams, in anticipation of e-cooling needs.

Applying ERL technology to test innovative concepts for even more efficient cooling techniques

See I. Ben-Zvi talk
Take-Away Message #2

- Ongoing investment in accelerator R&D at RHIC is having huge payoff (luminosities for RHIC-II science 5 years sooner, at much less cost), with the promise of more to come (e.g., pp luminosity improvement from electron lenses). The work creates new options for significant upgrades at reduced cost.

- Applications are not always foreseen at the time of the investment in innovative R&D, e.g., for ERL use in low-energy electron cooling for RHIC critical point search or in proof-of-principle test for coherent electron cooling, with big potential EIC payoff.
Ongoing Detector Upgrades are Critical to RHIC and RHIC-II Science Program

~1-2 new subsystems/year in PHENIX & STAR have immediate physics payoff: e.g., low-mass dileptons; CGC tests; W production triggering and cleanliness; heavy flavor physics; $\gamma$ - jet acceptance …

See Jacak, Xu, Ludlam and O’Brien talks for details.

Ongoing suite of upgrades should be completed ~2013-14.

Closer BNL supervision & consulting on project management issues needed to smooth recent glitches (see O’Brien).
## Tentative RHIC Run Plan Following 2008 PAC Recommendations
(assumes 6-month FY09 CR, 2-species runs in FY10-14 & best info on detector upgrade schedules)

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Colliding Beam Species/Energy</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>200 GeV p+p</td>
<td>~12 physics weeks to complete 200 GeV $A_{LL}$ measurements – could be swapped with 500 GeV Run 10 if &gt;6-month FY09 CR likely; STAR DAQ1000 fully operational</td>
</tr>
<tr>
<td>2010</td>
<td>500 GeV p+p</td>
<td>~5-6 physics weeks to commission collisions, work on polarization &amp; luminosity and obtain first W production signal to meet 2011 RIKEN milestone</td>
</tr>
<tr>
<td></td>
<td>200 GeV Au+Au</td>
<td>9-10 physics weeks with PHENIX HBD, STAR DAQ1000 &amp; TOF permits low-mass dilepton response map and 1st HI collision test of transverse stochastic cooling (one ring)</td>
</tr>
<tr>
<td>2011</td>
<td>Au+Au at assorted low E</td>
<td>1st energy scan for critical point search, using top-off mode for luminosity improvement – energies and focus signals to be decided; commission PHENIX VTX (at least prototype)</td>
</tr>
<tr>
<td></td>
<td>200 GeV U+U</td>
<td>1st U+U run with EBIS, to increase energy density coverage</td>
</tr>
<tr>
<td>2012</td>
<td>500 GeV p+p</td>
<td>1st long 500 GeV p+p run, with PHENIX muon trigger and STAR FGT upgrades, to reach ~100 pb$^{-1}$ for substantial statistics on W production and $\Delta G$ measurements</td>
</tr>
<tr>
<td></td>
<td>200 GeV Au+Au</td>
<td>Long run with full stochastic cooling, PHENIX VTX and prototype STAR HFT installed; focus on RHIC-II goals: heavy flavor, $\gamma$-jet, quarkonium, multi-particle correlations</td>
</tr>
<tr>
<td>2013</td>
<td>500 GeV p+p</td>
<td>Reach ~300 pb$^{-1}$ to address 2013 DOE performance milestone on W production</td>
</tr>
<tr>
<td></td>
<td>200 GeV Au+Au or 2nd low-E scan</td>
<td>To be determined from 1st low-E scan and 1st upgraded luminosity runs, progress on low-E e-cooling, and on installation of PHENIX FVTX and NCC and full STAR HFT</td>
</tr>
<tr>
<td>2014</td>
<td>200 GeV Au+Au or 2nd low-E scan</td>
<td>Run option not chosen for 2013 run – low-E scan addresses 2015 DOE milestone on critical point, full-E run addresses 2014 ($\gamma$-jet) and 2016 (identified heavy flavor) milestones. Proof of principle test of coherent electron cooling.</td>
</tr>
<tr>
<td></td>
<td>200 GeV p+p</td>
<td>Address 2015 DOE performance milestone on transverse SSA for $\gamma$-jet; reference data with new detector subsystems; test e-lenses for p+p beam-beam tune spread reduction</td>
</tr>
</tbody>
</table>
## Run Plan, Detector & Luminosity Upgrades Address All New RHIC-Related Performance Milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>#</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>HP8</td>
<td>Measure flavor-identified $q$ and $\bar{q}$ contributions to the spin of the proton via the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>longitudinal-spin asymmetry of $W$ production.</td>
</tr>
<tr>
<td>2013</td>
<td>HP12</td>
<td>Utilize polarized proton collisions at center of mass energies of 200 and 500 GeV, in combination</td>
</tr>
<tr>
<td></td>
<td>(update</td>
<td>with global QCD analyses, to determine if gluons have appreciable polarization over any range of</td>
</tr>
<tr>
<td></td>
<td>of HP1)</td>
<td>momentum fraction between 1 and 30% of the momentum of a polarized proton.</td>
</tr>
<tr>
<td>2015</td>
<td>HP13</td>
<td>Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering</td>
</tr>
<tr>
<td></td>
<td>(new)</td>
<td>and those observed in deep-inelastic lepton scattering.</td>
</tr>
<tr>
<td>2014</td>
<td>DM9</td>
<td>Perform calculations including viscous hydrodynamics to quantify, or place an upper limit on, the</td>
</tr>
<tr>
<td></td>
<td>(new)</td>
<td>viscosity of the nearly perfect fluid discovered at RHIC.</td>
</tr>
<tr>
<td>2014</td>
<td>DM10</td>
<td>Measure jet and photon production and their correlations in $A\approx$200 ion+ion collisions at</td>
</tr>
<tr>
<td></td>
<td>(new)</td>
<td>energies from $\sqrt{s_{NN}} = 30$ GeV up to 5.5 TeV.</td>
</tr>
<tr>
<td>2015</td>
<td>DM11</td>
<td>Measure bulk properties, particle spectra, correlations and fluctuations in Au + Au collisions at</td>
</tr>
<tr>
<td></td>
<td>(new)</td>
<td>$\sqrt{s_{NN}}$ between 5 and 60 GeV to search for evidence of a critical point in the QCD matter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>phase diagram.</td>
</tr>
<tr>
<td>2016</td>
<td>DM12</td>
<td>Measure production rates, high $p_T$ spectra, and correlations in heavy-ion collisions at $\sqrt{s_{NN}} = 200$ GeV for identified hadrons with heavy flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma.</td>
</tr>
<tr>
<td>2018</td>
<td>DM13</td>
<td>Measure real and virtual thermal photon production in $p + p$, $d + Au$ and $Au + Au$ collisions at energies up to $\sqrt{s_{NN}} = 200$ GeV.</td>
</tr>
</tbody>
</table>

N.B. Some will be missed if budgets do not permit 2 species/year runs in FY10-14
Where Do Heavy-Ion Collisions at LHC Fit In?

LQCD, Z. Fodor, Lattice 2007

RHIC

⇒

"perfect liquid"

LHC

Pb+Pb

~ RHIC

Ideal gas

Does matter still behave as an ideal liquid, or does shear viscosity grow from RHIC?

~ LHC

Some pump/probe tools get sharper at LHC -- e.g., full jet reconstruction/resolution -- but effects of interest (parton E loss) may be small or vanishing perturbations: LHC is exploratory.

How does hadron multiplicity grow? ⇒ info on initial state
Take-Away Message #3

- We are developing detailed strategic planning to optimize the impact of RHIC results during period when LHC HI starts. RHIC’s versatility, creative accelerator physicists, aggressive detector upgrade plans are critical to the success of this plan, as are budgets sufficient to run two beam species per year.

- RHIC will focus on systematic measurements to enhance understanding and discovery potential: quantifying properties of perfect liquid; searching for QCD critical point; improving constraints on polarization of gluons and sea antiquarks in a polarized proton.

- RHIC-II science continues well beyond 6-year run plan shown, fueled by further possible luminosity improvements from stochastic cooling upgrades (HI) and electron lenses (pp).
Making It All Happen, in 3 Acts...

I. Push time scale for RHIC-II science program earlier than Long Range Plan (~2017 start)

   -- with stochastic cooling, luminosity upgrade by 2012; detector upgrades ongoing, all completed by ~2014

II. Formulate upgrade plan for ~2016-2021 period

   -- e.g., 1st stage toward EIC; or AGS precision experiments

III. Make EIC science case and technical feasibility more compelling by next LRP (~2012-13?), for implementation in early 2020’s

   -- deepen (more transformational, less incremental) and broaden (add electroweak symmetry tests) science case; grow e-A experimental community; continue aggressive R&D program; consider staging strategies; work with JLab to move toward optimized design.
Intermediate-Term Possibilities: 1st (Medium Energy) Stage of EIC?

MEIC with 2 GeV ERL @ IP2 ⇒ DIS w/ inverse kinematics

~$145M (FY07) without new IP2 detector

- Would enable 2 GeV $\vec{e}$ on 100 GeV/N heavy ions and 250 GeV $\vec{p}$
- First look at saturation surface for nuclei, emphasizing diffraction tests of high gluon occupancy
- e-p program emphasizing detection of target fragments to probe spin-dependent correlations in proton internal wave function
- Need $\mathcal{L} \sim 10^{33}$ cm$^{-2}$s$^{-1}$ to be competitive? Develop science case.
- Most equipment would be reused later in full EIC
Planning for the Full EIC

- Considering various layouts & staging scenarios (V. Litvinenko)
- Reuse most equipment from medium-energy stage
- Keep A+A and p+p options alive
- Reduce demand on \( I(\text{pol'd e}) \) via coherent e-cooling of ion beams

Subsequent stages/alternative layouts could increase e-beam & ion-beam energies and \( L \) from nominal \( 10 \times 250 \text{ GeV}, \sim 4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \text{ e+p} \)

Brookhaven Science Associates
Take-Away Message #4

- Serious consideration of intermediate-term RHIC upgrades following the current suite, but preceding eRHIC, is just beginning. Innovative accelerator concepts offer hope of good match among technology, cost, science impact and path toward a longer-term future.

- Optimal staging scenarios for EIC require careful consideration of the science programs enabled, and that is just beginning.
Responses to 2007 S&T Recommendations: I

BNL should develop a plan with an aggressive schedule to demonstrate feasibility of transverse and longitudinal cooling with bunched beams. This plan should be submitted to DOE by December 31, 2007.

Plan fueled by detailed particle tracking simulations developed (M. Blaskiewicz) to reproduce observed behavior of longitudinal cooling:

- Longitudinal cooling in blue + 1st transverse plane in yellow installed for Run 9
- Test L-T interaction and sufficiency of 1 transverse plane per ring in Run 9 (CR ⇒ Run 10)
- Transverse plane for blue & 56 MHz SRF upgrade installed for Run 11 (FY09 CR ⇒ Run 12?)

More detail in T. Roser talk & accel. breakout
Responses to 2007 S&T Recommendations: II

The PHENIX and STAR collaborations should perform an evaluation to improve the ratio of data recorded with respect to delivered beam luminosity. All factors should be analyzed, including the efficiency of detector operations.

*Three main contributing factors to present ratio $\approx \frac{1}{4} - \frac{1}{3}$:*

- **Vertex cuts:** RHIC upgrades (incl. 9 MHz RF for pp) should reduce collision diamond $\Rightarrow \sim x 1.5$ improvement for triggers that retain present $\pm 30$ cm cut; maintain $\sim 50\%$ loss for triggers with $\pm 10$ cm cut tailored to new microvertex detectors

- **Dead time:** Factor $\sim 2$ improvement for rare STAR triggers with DAQ1000 upgrade (complete Run 9); plans to upgrade PHENIX DAQ/Trigger to maintain present $\sim 90\%$ livetime with higher luminosities

- **Detector up-time:** Only modest improvements to present $\sim 75\%$ from improved efficiency of detector operations + longer heavy-ion stores with stochastic cooling lifetime improvement

More in PHENIX, STAR talks + detector breakout session
Responses to 2007 S&T Recommendations: III

BNL should develop and document a detailed plan with milestones that demonstrates the experimental sensitivity for the proposed proton spin measurements between 2008 and 2013 using the anticipated accelerator design capabilities and detector performance as a planning base.

New Spin Report to be presented by G. Bunce -- based on performance to date + new simulations + expectations of machine improvements -- all 3 RHIC spin DOE performance milestones should be met.

Figure 14: Projected uncertainties for 300 pb⁻¹ and 70% beam polarization of $A_L$ as a function of $E_T$ in the mid-rapidity acceptance region of the STAR BEMC ($-1 < \eta < 1$).
Responses to 2007 S&T Recommendations: IV

Considering the magnitude of the resources required for the lattice gauge calculations envisioned by the Lattice Gauge Theory (LGT) group, RHIC should develop a plan for obtaining the computational capabilities to realize the scientific goals. This plan should be developed in the context of the National Lattice Gauge Program of the U.S. Quantum Chromo Dynamics (USQCD) collaboration...

**BNL high-temperature Lattice Gauge work and hardware plans are fully integrated with USQCD Collaboration:**

- **F. Karsch** is member of USQCD Scientific Program Committee, strong contributor to 2007 White Paper on plans in QCD Thermodynamics
- **LQCD II project** would distribute ~$23 M over FY10-14 for upgraded hardware and operations of computers for USQCD ~equally among Fermilab, JLab and BNL
- **Next BNL QCD computer could be Blue Gene/Q -- not decided yet**

More detail in F. Karsch talk in Theory breakout session
Focus Points & Issues for this Review:

- Does Panel concur that:
  - A clear strategic plan has been developed to maintain strong RHIC science impact during LHC HI turn-on and beyond?
  - The balance recently maintained and planned between operating weeks vs. upgrades + R&D is based on a long-term view essential even in tight budget times?
  - The updated RHIC Spin plan presents goals that are achievable and compelling?

- Are plans to improve monitoring and consulting on detector upgrade projects sufficient to ensure progress on the needed aggressive timelines?

- Are plans to improve DAQ/trigger capabilities, RCF capacity and access to distributed computing resources sufficient to keep up with planned luminosity increases?
Backup Slides
Detector Upgrades in Progress

- Both STAR and PHENIX upgrading DAQ/trigger to handle higher data rates, select rarer probes with upgraded luminosity

- PHENIX specifically upgrading muon trigger for W production program

- STAR Forward Meson Spectrometer detects photons at large rapidity to probe gluon saturation effects in d+Au, spin effects for forward $\pi^0$ and $\gamma$, ...

- STAR Time-of-Flight MRPC detector enhances particle ID, especially useful for QCD critical point search
Possible EIC Staging (as per V. Litvinenko)

**MEIC - RHIC + ERL**
inside RHIC tunnel (2 GeV $e^+$ × 250 GeV $p$ @ L $\sim 10^{32}$ cm$^{-2}$s$^{-1}$)

- $2 \times 200$ m SRF linac
- 10-12.5 MeV/m
- 4-5 GeV per pass

**eRHIC phase I:** add SRF linacs in RHIC tunnel + upgrade RHIC magnets $\Rightarrow$ 20-30 GeV $e^+$ × 325 GeV $p$ @ L $\sim 4 \times 10^{33}$ cm$^{-2}$s$^{-1}$ or 120 GeV/N Au @ L $\sim 10^{31}$ cm$^{-2}$s$^{-1}$

- ePHENIX
- eSTAR

**eRHIC phase II:** Luminosity upgrade to $\sim 10^{35}$ (crab cavities, etc.) at reduced ($\sim 10$ GeV e) energy for exclusive reactions

5 (6) vertically separated passes
Intermediate-Term Possibilities: CeC-Fueled Upgrade in $\vec{p}+\vec{p}$ Luminosity?

- $\tau_{cool}$ for $p$ @ RHIC $\sim$ 0.1-0.3 h; $\mathcal{L}_{pp}$ improvement needs reduced beam-beam tune spread
- Enhanced $\mathcal{L}$ would facilitate: DY test of QCD for transverse spin asym.; parity violation in hard jet prod’n; $W$-charm coinc. to probe strangeness contribution to proton spin; etc.
- Can detectors handle higher rates, pileup?

Planning proof of principle demo of coherent e-cooling in RHIC, using $\sim$20 MeV e from ERL already being developed + 40 GeV/N Au beams.

If successful, consider CeC for $\vec{p}$ beams at RHIC $\rightarrow$ EIC.
Detector & Luminosity Upgrades \Rightarrow New Physics Milestones

Measure hadron suppression and flow for identified heavy-quark mesons, possibly baryons ($\Lambda_c$)

STAR projections for $D^0$ central-to-peripheral yield ratio

PHENIX projections for $J/\psi$ elliptic flow

Addresses new 2016 NP milestone (DM12) covering “identified hadrons with heavy-flavor valence quarks to constrain the mechanism for parton energy loss in the quark-gluon plasma”
Detector & Luminosity Upgrades ⇒ New Physics Milestones

- Calibration of light-quark energy loss via $\gamma$-tagging (DM10, 2014)
- Definitive map of quarkonium melting, to search for effects of deconfinement and probe the (heavy) quark-quark interaction in the medium

**RHIC II AuAu 20 nb$^{-1}$**

- PHENIX projections of $\gamma$-jet yield @ RHIC-II L

**Calibration of light-quark energy loss via $\gamma$-tagging (DM10, 2014)**

**Definitive map of quarkonium melting, to search for effects of deconfinement and probe the (heavy) quark-quark interaction in the medium**
**RHIC-II Science: Quantifying Properties of the Perfect Liquid**

I. Enhanced luminosity + detector upgrades enable rare probe studies of yield and flow of quarkonia (qq̅ systems), sensitive to color screening and parton equilibration/coalescence in the quark-gluon plasma.
II. Facilitate rare- and multi-particle correlation measurements: $\gamma + \text{jet}$ to quantify energy loss transport coefficient; multi-hadron to study possible Mach cone, extract speed of sound.

III. Improve exp’t-theory comparison of particle-identified (esp. heavy quark) flow, to quantify shear viscosity.

IV. Improve fluctuation measurements at low collision $E$ to search for QCD critical point.

LHC and RHIC-II HI results should be complementary & mutually stimulating: similar matter produced? How do properties evolve? Thermalization consistent?

Quantitative interpretation of both requires coherent theory assault!
One Example

Uranium beams with EBIS extend the RHIC range.
A longitudinally polarized deuteron beam is stored in the EDM ring, for $\sim 10^3$ s.

The strong effective $E^\times B$ field will precess the deuteron spin out of plane if it possesses a non-zero EDM.

<table>
<thead>
<tr>
<th>System</th>
<th>Current limit [e·cm]</th>
<th>Future goal</th>
<th>Neutron equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron</td>
<td>$&lt; 1.6 \times 10^{-26}$</td>
<td>$\sim 10^{-28}$</td>
<td>$10^{-28}$</td>
</tr>
<tr>
<td>$^{199}$Hg atom</td>
<td>$&lt; 2 \times 10^{-28}$</td>
<td>$\sim 2 \times 10^{-29}$</td>
<td>$10^{-25}$-$10^{-26}$</td>
</tr>
<tr>
<td>$^{129}$Xe atom</td>
<td>$&lt; 6 \times 10^{-27}$</td>
<td>$\sim 10^{-29}$-$10^{-33}$</td>
<td>$10^{-26}$-$10^{-29}$</td>
</tr>
<tr>
<td>Deuteron nucleus</td>
<td>$\sim 10^{-29}$</td>
<td>$3 \times 10^{-29}$</td>
<td>$5 \times 10^{-31}$</td>
</tr>
</tbody>
</table>

If nEDM is discovered at $10^{-28}$ e·cm level?

- If $\theta$ is the source of the EDM, then
  \[ d_D(\theta)/d_n(\bar{\theta}) \approx 1/3 \implies d_D \approx 3 \times 10^{-29} \text{ e·cm} \]

- If SUSY is the source of the EDM (isovector part of T-odd N-forces), then
  \[ d_D(\theta)/d_n(\bar{\theta}) \approx 20 \implies d_D \approx 2 \times 10^{-27} \text{ e·cm} \]

The deuteron EDM is complementary to neutron and in fact has better sensitivity.
The strongest hint for a TeV-scale modification of the Standard Model originates from the anomalous magnetic moment of the muon.

- Proposed new exp’t to 0.1 ppm ⇒ 6σ sensitivity would need ~$55M (0.25 ppm “fast” version ~$30M)
- Ring and expertise exist at BNL (AGS ops costs shared with NP?); FNAL version offers some technical advantages in muon accumulation; J-PARC?
- BNL wants to see the physics done: will support regardless of location

\[
\Delta a_\mu (\text{expt-thy}) = (29.5 \pm 8.8) \times 10^{-10} (3.4 \sigma)
\]

Studying New Matter...

The matter produced in near-central ion-ion collisions at RHIC flows as a more nearly perfect (very low shear viscosity) liquid than any previously known.

\[ \therefore \text{RHIC probes matter in the very strong coupling limit of QCD: LQCD} \Rightarrow \text{quantitative theory for static properties; AdS/CFT} \Rightarrow \text{qualitative insight + gravity connection.} \]

Questions for the (near) future: how close is shear viscosity/entropy density ratio to conjectured quantum lower limit? What happens to bulk viscosity? How does viscosity evolve with temperature? How do its other quantitative properties inform theoretical approaches to QCD matter?

Needs RHIC-II luminosities & upgrades
\( \vec{p} - \vec{p} \) at RHIC addresses:

1) What does the share of \( \vec{p} \) spin carried by gluons and sea quarks/antiquarks reveal about effective degrees of freedom?

2) How is parton orbital motion inside \( \vec{p} \) manifested in transverse spin asymmetries?

\( \vec{e} - \vec{N} \) at EIC would exploit scaling violations & exclusive reactions to extend study to completely gluon-dominated region at low momentum fraction.
EIC probes weak coupling regime of very high gluon density, where gauge boson occupancy >> 1. All ordinary matter has at its heart an intense, semi-classical force field -- can we demonstrate its universal behavior?

Cold Matter

Search for supersymmetry @ LHC, ILC (?): seeking to unify matter and forces

Electron-Ion Collider: reveal that Nature blurs the distinction

Deep inelastic scattering @ HERA ⇒

Gluons dominate the soft constituents of hadrons! But density must saturate…

EIC probes weak coupling regime of very high gluon density, where gauge boson occupancy >> 1. All ordinary matter has at its heart an intense, semi-classical force field -- can we demonstrate its universal behavior?