The near- and mid-term future of RHIC, EIC and sPHENIX

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Brookhaven National Laboratory

Quark Matter 2022, Krakow, Poland
“Near” and “Mid” and caveats

Relevant times: from days to years

Many recent developments regarding RHIC & EIC

Compilation of public information with (hopefully) helpful context

Plans are always contingent on many factors, such as annual budgets
US Nuclear Science priorities

The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.
There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: (1) **Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales.** The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) **Map the phase diagram of QCD with experiments planned at RHIC.**
Beam Energy Scan II 2019-2021 with STAR
- Low energy ($\sqrt{s_{NN}} = 7.7, 9.2, 11.5, 14.5, 19.6$ GeV) Au+Au runs using electron cooling to increase luminosity
- Fixed target runs at (3.0), 3.5, 3.9, 4.5, 5.2, 6.2, 7.7 GeV
- Search for signs of critical phenomena in event-by-event fluctuations

Forward spin run 2022 with STAR
- 500 GeV p+p enhanced by forward upgrades of STAR
- Spin physics measurements complementary to EIC

Runs with the addition of sPHENIX 2023-25
- Full energy ($\sqrt{s_{NN}} = 200$ GeV) Au+Au, p+p, p+Au
- Precision measurements of fully resolved jets and Upsilon states

Accelerator R&D with strong connection to EIC
RHIC Run Plan 2021-2025

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Accelerator R&D with strong connection to EIC

*actually 508 GeV
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Accelerator R&D with strong connection to EIC
Perspective of the BNL NPP PAC

2.3 Discussion and Recommendations for RHIC Runs 23-25

RHIC is poised to deliver, in Runs 23-25, the culmination of the RHIC scientific program on hard probes. It is unusual to build an entirely new detector for the concluding three years of a 25 year program, but the scientific case for doing so that was made in the 2015 Long Range Plan is sufficiently compelling. The PAC looks forward with great anticipation to the insights into the microscopic structure of the quark-gluon plasma that the sPHENIX detector has been designed to deliver. *The top overall priority in planning for these three runs is to commission the sPHENIX detector and to achieve its scientific program.* The investment that the DOE, BNL, and the collaboration have made in sPHENIX means that these three years should be seen and managed as the first three years of a major, brand new, high impact, experimental effort, even though at the same time they are anticipated to be the last three years of the overall RHIC program. BNL and DOE should do everything possible to provide the running time needed in order for sPHENIX to fulfill the goals of its scientific program, as recommended by the 2015 LRP.

At the same time, we commend the STAR collaboration for having developed a complementary science program that takes advantage of new STAR detector capabilities (detector elements developed for the BES program; the forward upgrades developed for Run 22) that will add further scientific impact during these run years.
Perspective of the BNL NPP PAC

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LHC future schedule

Subject of following talk by Jochen Klein
RHIC & EIC future schedule

sPHENIX & STAR

sPHENIX installation

Run-22

Today

EIC construction (accelerator and detector)

EIC operation

LHC Run 3

LHC LS3

LHC Run 4

near-term

mid-term

2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033
sPHENIX program

Instrumentation and fast DAQ for differential, scale-dependent observables

Probes with resolution below thermal scale

Effective d.o.f.’s ➞ observed QGP properties

Temperature dependence of QGP transport coefficients

Cold QCD, spin physics also

Jet structure
vary momentum/angular scale of probe

Quarkonium spectroscopy
vary length scale of probe

Parton energy loss
vary mass/momentum of probe

YeonJu Go (U. Colorado, Boulder) "The sPHENIX Experiment at RHIC" Wednesday, T15-4
**sPHENIX run plan**

n.b.: specifics depend on ALD decisions and actual year-by-year budgets

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>$\sqrt{s_{NN}}$ [GeV]</th>
<th>Cryo Weeks</th>
<th>Physics Weeks</th>
<th>Rec. Lum.</th>
<th>Samp. Lum.</th>
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<tbody>
<tr>
<td>2023</td>
<td>Au+Au</td>
<td>200</td>
<td>24 (28)</td>
<td>9 (13)</td>
<td>3.7 (5.7) nb$^{-1}$</td>
<td>4.5 (6.9) nb$^{-1}$</td>
</tr>
<tr>
<td>2024</td>
<td>$p^{+}p^{+}$</td>
<td>200</td>
<td>24 (28)</td>
<td>12 (16)</td>
<td>0.3 (0.4) pb$^{-1}$ [5 kHz]</td>
<td>45 (62) pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.5 (6.2) pb$^{-1}$ [10%-str]</td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td>$p^{+}$+Au</td>
<td>200</td>
<td>–</td>
<td>5</td>
<td>0.003 pb$^{-1}$ [5 kHz]</td>
<td>0.11 pb$^{-1}$</td>
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<td></td>
<td></td>
<td></td>
<td>0.01 pb$^{-1}$ [10%-str]</td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td>Au+Au</td>
<td>200</td>
<td>24 (28)</td>
<td>20.5 (24.5)</td>
<td>13 (15) nb$^{-1}$</td>
<td>21 (25) nb$^{-1}$</td>
</tr>
</tbody>
</table>

141 billion Au+Au events with $|z| < 10$ cm recorded
sPHENIX $p_T$ reach for $\sqrt{s_{NN}} = 200$ GeV

Au+Au: record 2/3 of available luminosity while remaining 90% live statistics for untriggered observables employ triggers to augment high $p_T$ direct $\gamma$, other channels
b-jet $R_{AA}$ and elliptic flow

Secondary vertex and track counting approaches to b-tagging shown to be viable

Event plane detector
di-jet modification: b-jets and light jets

\[ R_{AA}^{bb} \]

**sPHENIX Projection, b-jet, 0-10% Au+Au, Year 1-3**

\[ |\eta_{1,2}| < 0.7, |\Delta\phi_{1,2}| > 2\pi/3, p_{T,1} > 15 \text{ GeV/c}, p_{T,2} > 10 \text{ GeV/c} \]

\[ p+p: 62 \text{ pb}^{-1} \text{ samp.}, 60\% \text{ Eff.}, 40\% \text{ Pur.} \]

\[ \text{Au+Au: 21 nb}^{-1} \text{ rec.}, 40\% \text{ Eff.}, 40\% \text{ Pur.} \]

Kang et al, PRD 99, 034006 (2019), m=m\_med \_g \_med = 2.0 \_g \_med = 2.2 \_g \_med = 1.8

\[ R_{AA}^{bb} / R_{AA} \]

Open heavy flavor

$sPHENIX$ Projection, 0-10% Au+Au, Years 1-3
6.2 pb$^{-1}$ str. $p+p$, 21 nb$^{-1}$ rec. Au+Au

$R_{AA}$

$sPHENIX$ Projection, Years 1-3
- 6.2 pb$^{-1}$ str. $p+p$
- 21 nb$^{-1}$ rec. Au+Au, 0-10%
- STAR, Au+Au, 0-20%, PRL 124 (2020) 172301

Figure 7.5: Projected statistical uncertainties of nuclear modification factor $R_{AA}$ measurements of non-prompt/prompt $D^0$ mesons (left) and $b$-jets (right) as a function of $p_T$ in 0–10% central Au+Au collisions at $p_{NN} = 200$ GeV from the three-year sPHENIX operation.

Left: the solid green curve are averaged $R_{AA}$ for pions and the solid blue line is from a model calculation of $R_{AA}$ for $B$ mesons over several models $[28, 29, 30, 31]$, which maps to the dashed blue line for $D^0$-meson from $B$ decay.

Right: the curves represents a pQCD calculations with two coupling parameters to the QGP medium, $g_{med}$ $[32]$, and the blue band is from a recent calculation based on the LIDO transport model $[33]$.

Figure 7.6: Projected statistical uncertainties of $v_2$ measurements of non-prompt/prompt $D^0$ mesons (left) and $b$-jets (right) as a function of $p_T$ in Au+Au collisions at $p_{NN} = 200$ GeV. Left: the blue dotted line is from best fit of RHIC data, and the black line is for $B$-meson assuming $m_T$ scaling in $v_2$.

$sPHENIX$, equipped with a state-of-the-art vertex tracker and high rate streaming DAQ, will bring key heavy-flavor measurements at RHIC fully into the precision era and place stringent tests on models describing the coupling between heavy quarks and the medium. In the first three years of operation, sPHENIX will enable $B$-meson and $b$-jet measurements covering the wide transverse momentum range $2 < p_T < 40$ GeV, as shown in Figures 7.5 and 7.6. The left panel of Figure 7.5 shows the $B$-meson ($D^0$ from $B$) nuclear modification measurements covering the kinematic range $p_T$.
Upsilon spectroscopy

Backgrounds, pileup from 50 kHz collision rate
E/p matching; >100 π rejection with 90% efficiency
(Superconducting magnet) Superconducting magnet

Intermediate Tracker

MAPS Vertex detector

Hadronic Calorimeter

Electromagnetic Calorimeter

Time Projection Chamber

Event Plane Detector

Minimum-bias detector

TPC Outer Tracker

support carriage

cryogenic chimney

outer HCal

inner HCal

EMCal

TPC

* sEPD (Event Plane Detector),
* MBD (Minimum-bias detector),
* TPOT (TPC Outer Tracker) not shown in the figure
Carbon fiber support and service structures designed for sPHENIX

staves built at CERN ALICE ITS IB design

MIT students at CERN developing QA software for use by all

LANL, MIT, LBNL
EMCal

64th – and final – EMCal sector finished on Friday

Final W/Sci-fi blocks

UIUC, Fudan, PKU, CIAE
Instrumenting outer HCal sectors at BNL

Historical note: where AGS fixed target experiments were located
Drone footage
sPHENIX collaboration/project

82 institutions, nearing 400 collaborators

co-spokespersons:
  Gunther Roland (MIT), DM

project director:
  Ed O’Brien (BNL)

first collisions: February 2023
From RHIC to EIC

Polarized electron beams + existing hadron accelerator ⇒ high-luminosity polarized electron-ion collisions

BNL and JLab are partners in managing EIC project, with major worldwide contributions

Technical capability for collisions at two IRs; one detector is part of EIC project

Scale of total project: $1.7–2.8B. Biggest project undertaken by DOE ONP

n.b. ion-ion capability ends with final RHIC run

Responses to EIC call for proposals

ATHENA Detector Proposal
A Totally Hermetic Electron Nucleus Apparatus proposed for IP6 at the Electron-Ion Collider

The ATHENA Collaboration
December 1, 2021

CORE - a CCharmic detector for the EIC

ECCE Comprehensive Chromodynamics Experiment Collaboration Detector Proposal

A view of the jet detector capable of fully exploiting the science potential of the EIC, realised through the use of smart instrumentation and infrastructure, to be ready by project CD 4A.

December 2, 2021
EIC Detector Proposal Advisory Panel

co-chairs:
Patricia McBride
Rolf Heuer

6. Recommendations:

The panel unanimously recommends ECCE as Detector 1. The proto-collaboration is urged to openly accept additional collaborators and quickly consolidate its design so that the Project Detector can advance to CD2/3a in a timely way.

The panel supports the case for a second EIC detector, however, given the current funding and available resources, the committee finds that a decision on Detector 2 should be delayed until the resources and schedule for the Project detector (Detector 1) are more fully realized.

cf. American Physical Society April Meeting: today 6pm CEST, Patricia McBride
“EIC Detector Design: Outcomes from the EIC Detector Proposals Advisory Committee”
EIC project perspective

The panel reviewed detector proposals from the three proto-collaborations

All three proposals received high marks

Concluded that ATHENA and ECCE satisfied the requirements

Recommended the ECCE detector proposal as the project detector

Noted that many collaborators are involved in multiple proposals and none of the proto-collaborations are currently strong enough to build the project detector

Strongly encouraged the three proto-collaborations to move forward together based on ECCE as the reference design for the EIC project detector

Expects the integration of new collaborators and new experimental concepts and technologies to improve physics capabilities, and to prepare the detector as part of the EIC project baseline, the next major DOE schedule milestone

Enthusiastically supported a second detector as needed to take full advantage of the unique capabilities of EIC facility

Expects the EIC User Community to come together in support of the project detector as well as a second detector.
Summary: the near- and mid-term future

Guided by the still current NSAC long range plan …

Beam energy scan completed
Successful STAR upgrades for BES and forward measurements
sPHENIX installation well underway; first collisions February 2023
Major new NP facility EIC progressing toward construction start
Bonus material
Inner HCal complete at BNL