Critical Decision-1/3A for the sPHENIX MIE Project
at Brookhaven National Laboratory
Office of Nuclear Physics
Office of Science

A. Purpose

The purpose of this paper is to document the review by the Office of Science (SC) Energy Systems Acquisition Advisory Board-equivalent for the Critical Decision 1 (CD-1), Approve Alternative Selection and Cost Range, and CD-3A, Approve Long Lead Procurements, for the Super Pioneering High Energy Nuclear Interaction experiment (sPHENIX) Major Item of Equipment (MIE) at Brookhaven National Laboratory (BNL).

B. Mission Need

The mission of the Office of Science (SC) is to deliver the scientific discoveries and major scientific tools that transform our understanding of nature and advance the energy, economic, and national security of the United States. SC accomplishes this mission through the direct support of research, construction, and operation of national scientific user facilities, and the stewardship of ten world-class national laboratories. The SC national laboratories collectively comprise a preeminent federal research system that develops unique, often multidisciplinary, scientific capabilities beyond the scope of academic and industrial institutions, to benefit the nation's researchers and national strategic priorities.

The Office of Nuclear Physics (NP) program plans, constructs, and operates major scientific user facilities and fabricates experimental equipment to serve researchers at universities, national laboratories, and industrial laboratories as part of its strategic mission. The program provides world-class, peer- reviewed research results in the scientific disciplines encompassed by the NP mission areas under the mandate provided in Public Law 95-91 that established the Department of Energy (DOE).

The DOE NP program addresses three broad, interrelated scientific thrusts in pursuit of its mission: Quantum Chromodynamics (QCD), Nuclei and Nuclear Structure and Astrophysics, and investigations of Fundamental Symmetries using neutrons and nuclei. sPHENIX addresses goals within the "QCD investigations" within the NP program. Over the last two decades, the heavy ion nuclear physics component of the QCD scientific thrust has focused on the discovery and characterization of the Quark Gluon Plasma (QGP): a form of matter believed to have last naturally existed in the universe approximately one microsecond after the Big Bang. Since the discovery of the QGP at the BNL RHIC over ten years ago, and subsequent confirmation by experiments at CERN's Large Hadron Collider (LHC), a number of important characteristics of the QGP have been measured. Though great progress has been made over the last twenty years, the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plan (LRP) identified a vital QGP-related research question that remains unaddressed. The field must "probe the inner workings of the quark gluon plasma by resolving the properties at shorter and shorter length scales." A virtually identical goal was recommended in the 2010 National Academy Study, "Nuclear Physics, Exploring the Heart of Matter." The sPHENIX MIE enables the pursuit of this directive at RHIC. The LRP states: "This program requires large samples of jets in different

energy regimes, with tagging of particular initial states, for example, in events with a jet back-to-back with a photon. The full power of this new form of microscopy will only be realized when it is deployed at both RHIC and the LHC, as jets in the two regimes have complementary resolving power and probe QGP at different temperatures, with different values of the length scale at which bare quarks and gluons dissolve into a near perfect liquid". sPHENIX is needed to make these measurements feasible. Neither the existing Solenoidal Tracker at the Relativistic Heavy Ion Collider (STAR) nor PHENIX experiments can make the required measurements with the necessary sensitivity.

Obtaining the scientific goals of sPHENIX has been identified by both the recent NSAC LRP and the National Academy study as needed to carryout NP's scientific mission. There is currently a gap in capabilities that needs to be addressed in order to reach those goals.

C. Preliminary Project Scope Baseline and Critical Decision Authorization

The preliminary scope baseline for the sPHENIX MIE is:

- A Time Projection Chamber (TPC), Electromagnetic Calorimeter (EMCal), and a Hadronic Calorimeter (HCal), all covering 2p in azimuth. The TPC and HCal have pseudorapidity coverage of $-1.1 \leq \eta \leq 1.1$. The EMCal has pseudorapidity coverage of $-0.85 \leq \eta \leq 0.85$;
- A Minimum Bias Trigger detector (MBD);
- Readout electronics to fully instrument the TPC, EMCal, HCal and MBD;
- A Data Acquisition system with the capability to readout the TPC, EMCal, HCal and MBD with an event rate and data-logging rate commensurate with the sPHENIX physics goals;
- A DAQ/Trigger system that can provide minimum bias and energy cluster triggers at a rate necessary to carry out the sPHENIX physics program in AA, pA and pp collisions at RHIC; and,
- Project Management to carry the project scope through to a successful on time and on budget completion.

This project will be declared complete (CD-4) when the defined scope is delivered to BNL and the Threshold Key Performance Parameters (KPPs) are satisfied through bench tests. Installation and integration of these delivered components and parallel activities associated with this sPHENIX MIE are not part of this project's scope to be delivered at CD-4.

The preliminary KPPs are shown in Table 1 below. The Threshold KPPs are the minimum parameters against which the project performance is measured at CD-4 project completion. The Objective KPPs are the stretch performance parameters that will be achievable within the CD-2 project scope, cost, and schedule performance measurement baseline when established. The KPPs are chosen because they comprise a set of minimum test results that once demonstrated, will allow one to conclude with confidence that sPHENIX will be able to meet its mission need after a period of commissioning, calibration, and data-taking. The KPPs define tests for each of the sPHENIX Level 2 deliverables. The tests will establish that the subsystems are working at a performance level that is consistent with their design. The difference between the Threshold and Objective KPPs is essentially the difference between the expected Level 2 subsystem performance soon after initial power-up and the performance after a period of debugging and maintenance.

System	Demonstration or Measurement	Threshold KPP's	Objective KPP's
Time Projection Chamber	Preinstall, Bench Test	≥ 90% live channels based on laser, pulser, cosmics	≥ 95% live channels based on laser, pulser, cosmics
Time Projection Chamber	Preinstall, Bench Test	Ion Back Flow ≤ 2% per Quad GEM Module	Same
Time Projection Chamber	Preinstall, Bench Test w/cosmics	≥ 90% single hit efficiency / mip track	≥ 95% single hit efficiency / mip track
Time Projection Chamber Front End Electronics	Preinstall, Bench Test	Cross talk ≤ 2% each channels	Same
EM Calorimeter	Preinstall, Bench Test	≥ 90% live channels based on LED, cosmics	≥ 95% live channels based on LED, cosmics
Hadronic Calorimeter	Preinstall, Bench Test	≥ 90% live channels based on LED, cosmics	≥ 95% live channels based on LED, cosmics
EM Calorimeter	Preinstall, Bench Test	Each sector with an absolute energy pre-calibration to a precision of ≤ 20% RMS	Same
Hadronic Calorimeter	Preinstall, Bench Test	Each sector with an absolute energy pre-calibration to a precision of ≤ 20% RMS	Same
Min Bias Trigger Detector	Preinstall, Bench Test	≥ 90% live channels based on laser. 120 ps/channels timing resolution w/ Bench Test	≥ 95% live channels based on laser. 100 ps/channels timing resolution w/ Bench Test
DAQ/Trigger	Event rate	10 kHz with random pulser	15 kHz with random pulser
DAQ/Trigger	Data Logging Rate	10 GBit/s with pulser	Same

Table 1: Preliminary Key Performance Parameters

In addition to these KPPs, preliminary Ultimate Performance Parameters (UPPs) have been defined. The UPPs are listed in Table 1a and describe the performance needed after project completion to realize the scientific goals of the project. These parameters are outside the project's scope.

Preliminary Ultimate Performance Parameters (UPPs)
Upsilon (1S) mass resolution ≤ 125 MeV
≥ 90% Tracking Efficiency
≤ 10% momentum resolution at 40 GeV /c
≤ 150% / √Ejet jet energy resolution for R=0.2 jets
≤ 8% single photon energy resolution at 15 GeV

Table 1a: Preliminary Ultimate Performance Parameters. UPPs for measurements made at 10% central Au+Au RHIC events at the average RHIC store luminosity.

D. Alternative Analysis

Seven alternatives were studied to meet the mission need. The seven alternatives were:

(1) Use the existing STAR detector.
(2) Upgrade the STAR detector.
(3) Upgrade PHENIX to the sPHENIX detector.
(4) Build a new detector at RHIC.
(5) Perform the measurement at CERN with an LHC detector.
(6) Use other detector technologies.
(7) Do nothing.

The total life cycle costs of Alternatives 1 through 7 were calculated and compared for operations requirements, budgetary considerations, and scientific impact. Each alternative was evaluated based on the criteria below:

a) Meet the science requirements described in the 2015 NSAC LRP identified a vital QGP-related research question that remains unaddressed: the field must "probe the inner workings of the quark gluon plasma by resolving the properties at shorter and shorter length scales."
b) Be available to leverage an existing Heavy Ion Collider (RHIC or LHC) and record data during an operating period consistent with the accelerators operating plan.
c) Deliver the required jet and heavy flavor measurement capability without undue risk and/or challenges.
d) Have reasonable life cycle cost (LCC).

The results are summarized in Table 2 below and are detailed in the sPHENIX Acquisition Strategy Appendix A, Conceptual Design: Analysis of Alternatives document. While the costs of Alternative 1 is less than Alternatives 2 and 3, it does not satisfy the mission need or address the capability gaps.

Analysis of Alternatives							
		Selection Criteria				Cost Range AY$: Construction + 5-year Ops + Decommissioning	Meets All Criteria
#	Alternative Description	Meets Mission Needs	Leverage in a Timely Fashion	Deliver Capability without Undue Risk or Challenge	Reasonable Life Cycle Costs		
1	**STAR Detector**	Poor	Poor	Poor	No	$60M	No
2	**Upgrade STAR Detector**	Excellent	Poor	Excellent	Yes	$95-105M	No
3	**Upgrade PHENIX Detector to sPHENIX**	Excellent	Excellent	Excellent	Yes	$86.5-94.5M	Yes
4	**Build New Detector at RHIC**	Excellent	Poor	Excellent	No	$130-140M	No
5	**Site with LHC Detector**	Poor	Poor	Poor	No	$60M	No
6	**Other Detector Technologies**	Poor	Poor	Excellent	No	$163.5-171.5M	No
7	**Do Nothing**	Poor	Poor	n/a	No	$0M	No

Table 2: Summary of Alternative Analysis

Table 2 summarizes the ranking of the seven alternatives to meet the selection criteria. A ranking of *poor* means the alternative did not meet the selection criteria, *good* means it was partially met, and *excellent* means it was fully met. Life cycle costs are ranked as *yes* or *no* to indicate if this selection criterion is met. We find some of the alternatives met the requirement for a reasonable LCC. Based on all criteria, Alternative (3) – Upgrade "PHENIX Detector to sPHENIX is the only option to meet all criteria and is the preferred choice.

E. Project Preliminary Cost and Schedule

The preliminary Total Project Cost (TPC) range is $24.2 to $34.5 million. Other Project Costs (OPC) of $6.423 million have been used for preliminary project documentation and LCC Analysis development. Table 3 shows the funding profile for this project.

Table 3 – Preliminary Funding Profile ($K)

Funding profile in AY k$								
	Prior Yrs.	**FY17**	**FY18**	**FY19**	**FY20**	**FY21**	**FY22**	**Total**
Pre-R&D								
R&D		1,513	4,260	350				**6,123**
CDR		100	200					**300**
Construction				5,310	9,524	5,080	213	**20,127**
TEC				**5,310**	**9,524**	**5,080**	**213**	**20,127**
OPC		**1,613**	**4,460**	**350**				**6,423**
TPC		**1,613**	**4,460**	**5,660**	**9,524**	**5,080**	**213**	**26,550**

Table 3: Funding Profile for Estimated Total Project Costs

The preliminary schedule baseline is shown in Table 4.

Table 4 – Schedule Baseline

Milestone	**Schedule Date**
CD-0, Approve Mission Need	9/16/2016 (A)
CD-1/3A, Approve Alternative Selection and Cost Range, Long Lead Procurements	Q4 FY 2018
CD-2/3, Approve Performance Baseline	Q4 FY 2019
CD-4, Approve Project Completion	Q1 FY 2023

Table 4 – Schedule Baseline

CD-4, "Approve Start of Full Operations," is scheduled for December 2023, which includes 14 months of schedule contingency.

WBS	Level 2 WBS Description	Cost in AY K$
1.1	Project Management	**1,470**
1.2	Time Projection Chamber	**3,484**
1.3	EM Calorimeter	**5,873**
1.4	Hadron Calorimeter	**3,464**
1.5	Calorimeter Electronics	**4,558**
1.6	DAQ/Trigger	**1,550**
1.7	Min Bias Trigger Detector	**132**
	Sub-total	**20,531**
	Contingency	**6,019**
	Total Project Cost	**26,550**

Table 5 – Cost Summary by WBS

F. Acquisition Strategy

Acquisition of sPHENIX will be conducted by Brookhaven Science Associates (BSA). BSA will direct the sPHENIX project management team in the execution of the project and delegate to the team its authority for project execution. BSA, as the Management and Operating (M&O) Contractor for BNL, will be responsible to DOE to manage and complete construction/fabrication of the MIE components. The basis for this choice and strategy is as follows:

- BSA has a DOE-approved procurement system with established processes and acquisition expertise needed to obtain the necessary components and services to build the components required for the upgrade.
- BSA has extensive experience in managing complex construction, fabrication and installation projects involving multiple National Laboratories, University and other partner institutions, including construction of the original PHENIX detector.

All actions will be competitive procurements unless specifically authorized by Procurement and sPHENIX project management. All actions will be in accordance with the DOE approved procurement policies and procedures.

NP will identify funding for the sPHENIX MIE to BSA via financial plans, to be managed by the sPHENIX MIE Office. The funding is made available through the redirection of RHIC operational funds. To accomplish this work, BNL will enter into agreements with collaborating institutions. The sPHENIX MIE Office will negotiate and implement Institutional Memoranda of Agreement (MOAs) and Statements of Work (SOW) between the sPHENIX MIE and the collaborating institutions. These MOAs and SOWs will specify the deliverables to be provided and the resources available, with funding anticipated to be provided incrementally on a yearly basis.

The sPHENIX MIE will also work closely with the RHIC Collider-Accelerator Department (C-AD) and BNL Physics Department managers to secure and manage the personnel and resources needed by the project to design, fabricate and install the technical components. The

project will work with these departments to develop MOAs with the performing organizations including the Magnet Division, Instrumentation and C-AD to document the resource requirements for staffing the sPHENIX MIE.

a. Long Lead Procurements

There are four long lead procurements identified for early procurement approval for CD-3A. The procurements have been planned in the resource-loaded schedule with estimates developed by the Level 2 Managers. The lead-time for each procurement is estimated as a planning package in the schedule. Advanced procurement plans have been generated for each procurement. The four long lead procurements are as follows:

1. Scintillating Tiles for the Outer HCal. (WBS 1.4): By the time of the order is placed, it will have been through five rounds of prototyping with the manufacturer. This part was selected approximately nine months ago after a successful beam test;
2. Scintillating Photomultipliers (SiPM) for the EMCal and HCal readout (WBS 1.5): This procurement is a catalog purchase of a Hamamatsu part. This component was selected about nine months ago after a successful beam test;
3. Scintillating Fibers Production order for the EMCal (WBS 1.3): This procurement is a catalog purchase from St Gobain/Bicron vendor. This component was selected about nine months ago after a successful beam test; and,
4. Tungsten Powder Production Order for the EMCal (WBS 1.3): This procurement is a commodity purchase. It was proven that a tungsten powder/ scintillating fiber works for the EMCal based on two successful beam tests at Fermi National Accelerator Laboratory (FNAL) and bench tests.

APP #	WBS/Description	Procurement	Lead Time	Direct Material $	Burd/Esc w/30% Cont.
33267	1.04.02.03 Outer HCAL Scintillating Tiles	Hadronic Calorimeter Scintillating Tiles	130 wd 1st Delivery	$1,327,066	$2,031,666
33270	1.05.01 Calorimeter Electronics - Optical Sensors	Silicon Photomulipliers (SiPM)	120 working days	$654,500	$872,164
33268	1.03.01.03 EMCAL Final Block Production	EMCal Scintillating Fibers	120 working days	$741,818	$1,136,368
33269	1.03.01.03 EMCAL Final Block Production	Tungsten powder for EMCal Block	60-80 working days	$1,289,490	$1,810,253
	Total Dollars			**$4,012,874**	**$5,850,451**

Table 6: Long Lead Procurement

The EMCal Scintillating Fiber is one procurement which will be phase funded. The tungsten powder for the EMCal blocks will be purchased as one procurement, and will be phase funded.

G. Environmental Strategy

The project complies with all requirements of the National Environmental Policy Act and its implementing regulations (10 Code of Federal Regulations 1021 and 40 Code of Federal Regulations 1500–1508). This action has been reviewed and determined to meet the requirements for a Categorical Exclusion (CX) determination and the CX was issued in May 2016. All environmental issues identified will be responsibly and economically addressed. No amendments are expected to be required for the existing site air and ground discharge permits. The facilities are existing and no environmental issues have been identified to date that would significantly impact the execution of this project. The environmental risk is low.

BNL has an Environmental Management System (EMS) certified to ISO 14001. Construction/fabrication subcontracts flow down requirements from the EMS. Oversight of

construction/fabrication activities will be conducted by BSA to ensure subcontractors are in compliance with EMS requirements. Throughout construction/fabrication, environmentally sensitive practices will be followed to reduce site disturbance, minimize waste, and improve indoor air quality. The sPHENIX MIE will include a waste management plan and an Indoor Air Quality Management Plan. Waste management requirements will include recycling and waste minimization actions.

H. Safety

The BNL Integrated Safety Management Plan is the governing institutional doctrine for all design, construction, and operation activities. BNL Integrated Safety Management holds line management, the BSA Project Director and BSA Project Manager, accountable to design and execute this project in a manner that will not compromise the safety or health of workers, the public, or the environment. Management of all aspects of the project to a "Zero Accident" goal is an integral part of the overall project mission. Safety through design will be the primary driver throughout the design phases of this project. Through management commitment and leadership, safety in the conduct of activities will be a fundamental driver through construction/fabrication and commissioning. Following the transition to operations, the operation and maintenance of the completed facility and installed equipment will become part of the existing BSA line management responsibilities.

I. Hazards Analysis

A Preliminary Hazards Analysis Report (PHAR) has been developed for this project and will serve as the basis for design safety criteria, remedial action needs, unique and routine construction/fabrication Environment, Safety & Health (ES&H) requirements, and facility startup ES&H requirements. Prior hazardous material removal efforts within the B1008 facility have been closed-out and all hazards including radioactive material have been removed. As design efforts continue, the Hazard Analysis Report will be updated as needed.

Not every ES&H hazard can be addressed through design alone; therefore, hazards must be identified, evaluated, and controlled at every operation and operational sub-task level. Phase Hazard Analysis by responsible supervision and crafts will be required of construction personnel. For construction/fabrication subcontractors, these task- and job-specific hazard analyses are contractual requirements.

J. Risk Management

A Preliminary Risk Management Plan (RMP) and Risk Registry has been prepared that identifies the potential risks and provides a comprehensive strategy for management of these risks. Adequate contingency has been included for these risks. The RMP and Risk Registry will be maintained to ensure that the project incorporates appropriate, efficient, and cost-effective measures to handle project risks and will be updated in support of CD-1/3A approval. The risks associated with this project and acquisition strategy are judged manageable. Detector design technology and fabrication methods for this type of facility exist and will be utilized. The probability of success of the sPHENIX MIE is considered high based on comparisons to similar facilities.

The major risks currently identified and the risk management approaches are identified in the Risk Registry. Risk Management meetings are held with the Level 2 Managers on a monthly basis after CD-1.

K. Security Considerations

Security of facilities and infrastructure is monitored and managed through the BNL Site Security Plan (SSP). The SSP recognizes controlled open areas, controlled areas, and property protection areas using physical controls and protective personnel. The facilities included in this project would be considered by the SSP as controlled open areas. This BNL/SC Program does not sponsor clearances and does not conduct classified research or generate classified matter.

Security considerations will continue to be evaluated and documented as the project moves forward, consistent with DOE G 413.3-3, "Safeguards and Security for Program and Project Management".

sPHENIX MIE at the
Brookhaven National Laboratory
CD-1/3A ESAAB

Submitted by:

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8/13/18
Date

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8-13-18
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CD-1/3A ESAAB
sPHENIX MIE at the Brookhaven National Laboratory

Recommendations:

The undersigned "Do Recommend" (Yes) or "Do Not Recommend" (No) approval of CD-1, for the Core Facility Revitalization Project as noted below.

ESAAB Secretariat, Office of Project Assessment	✓ Yes	No	8.16.18 Date
Representative, Office of Budget	Yes	No	Date
Representative, Safety and Security Policy (ES&H)	✓ Yes	No	8.16.18 Date
Representative, Safety and Security Policy (Security)	✓ Yes	No	8-16-18 Date
Representative, Operations Program Management (Facilities and Infrastructure)	✓ Yes	No	8/16/18 Date
Representative, Non-Proponent SC Program Office	Yes	No	Date
Representative, Non-Proponent Federal Project Director	X Yes	No	8/16/2018 Date

Approval:

Based on the information presented above and at this review, Critical Decision-1, Approve Alternative Selection and Cost Range, and Critical Decision-3A, Approve Long Lead Procurements as identified in Table 6, are approved and authorization is provided to proceed to Preliminary Design.

Timothy Hallman, Project Management Executive
Associate Director of the Office of Science for Nuclear Physics

8/16/2018
Date