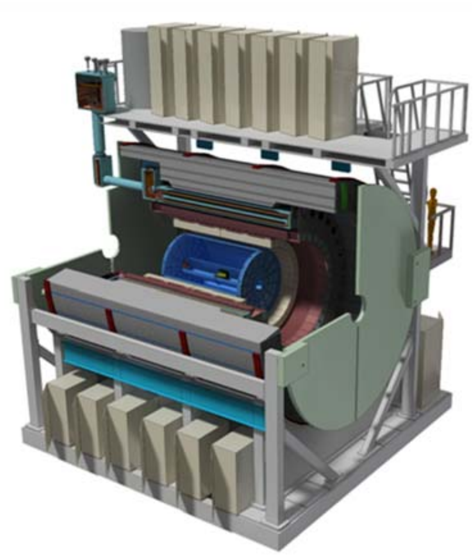
Acquisition Strategy for

sPHENIX MIE
Project # 17-N1

At Brookhaven National Laboratory

Office of Nuclear Physics
Office of Science
U.S. Department of Energy

August 2018



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Acquisition Strategy
sPHENIX Detector Upgrade Project at Brookhaven National Laboratory
Change Log

Revision History		
Rev.	**Date**	**Reason**
0	July 2018	Initial Issue.

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Acronym List

AY	Actual Year Dollars
ALD	Associate Laboratory Director
AS	Acquisition Strategy
ASE	Accelerator Safety Envelope
BHSO	Brookhaven Site Office
BNL	Brookhaven National Laboratory
BSA	Brookhaven Science Associates
C-AD	Collider-Accelerator Division
CD	Critical Decision
CDR	Conceptual Design Report
CERN	European Council for Nuclear Research
CR	Continuing Resolution
CY	Calendar Year
D&D	Decontamination & Decommissioning
DAM	Data Aggregation Module
DAQ	Data Acquisition
DOE	U.S. Department of Energy
EIA	Electronic Industries Alliance
EMCal	Electromagnetic Calorimeter
ES&H	Environmental Safety and Health
EVMS	Earned Value Management System
FNAL	Fermi National Accelerator Laboratory
FPD	Federal Project Director
FPM	Federal Program Manager
FY	Fiscal Year
GEM	Gas-Electron Multiplier
Gbps	Gigabits-per-second
HCal	Hadron Calorimeter
HQ	DOE Headquarters
IHCAL	Inner Hadron Calorimeter
IPR	Independent Project Review
IPT	Integrated Project Team
INTT	Intermediate Silicon Strip Tracker
ISM	Integrated Safety Management
ISMS	Integrated Safety Management System
kHz	kilohertz
KPP	Key Performance Parameter
L2	Level 2
L3	Level 3
LCC	Life Cycle Costs
LHC	Large Hadron Collider
LRP	Long Range Plan
MBD	Minimum Bias Trigger Detector
M&O	Management & Operating
MIE	Major Item of Equipment
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
NEPA	National Environmental Policy Act
NSAC	Nuclear Science Advisory Committee
NP	Nuclear Physics
NPP	Nuclear and Particle Physics
OHCal	Outer Hadron Calorimeter
ONP	DOE's Office of Nuclear Physics
OPA	Office of Project Assessment; Department of Energy

OPC	Other Project Costs
OPPO	Office of Project Planning and Oversight
OPS	Operations Program OSH Occupational Safety and Health
PARSIIe	Project Assessment and Reporting System IIe
PB	Performance Baseline
PC	Project Controls
PCR	Project Change Request
PEP	Project Execution Plan
PHENIX	Pioneering High Energy Nuclear Interaction eXperiment
PHAR	Preliminary Hazard Analysis Report
PKPP	Preliminary Key Performance Parameters
PPEP	Preliminary Project Execution Plan
PM	Project Manager
PME	Project Management Executive
PMG	Project Management Group
POB	Project Oversight Board
QA	Quality Assurance
QAP	Quality Assurance Plan
QCD	Quantum Chromodynamics
QGP	Quark Gluon Plasma
R&D	Research & Development
RHIC	Relativistic Heavy Ion Collider
RLS	Resource Loaded Schedule
RM	Risk Management
RMP	Risk Management Plan
SAD	Safety Assessment Document
SBMS	Standards Based Management System
SC	DOE Office of Science
SC Magnet	Superconducting Magnet
SiPM	Silicon Photomultiplier
SOW	Statement of Work
sPHENIX	Super Pioneering High Energy Nuclear Interaction eXperiment
STAR	Solenoidal Tracker at RHIC
SVAR	Security Vulnerability Assessment Report
TEC	Total Estimated Cost
TPC	Time Projection Chamber
UPP	Ultimate Performance Parameters
USI	Unreviewed Safety Issue
WBS	Work Breakdown Structure
WP	Work Packages

1.0 JUSTIFICATION OF 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 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 Astrophysics, and investigations of Fundamental Symmetries using neutrons and nuclei. sPHENIX supports the goals QCD investigations within the NP program. Over the last two decades, the heavy ion nuclear physics component of the QCD 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 1 microsecond after the Big Bang. Since the discovery of the QGP at the Brookhaven National Laboratory (BNL) Relativistic Heavy Ion Collider (RHIC) over ten years ago, and subsequent confirmation by experiments at CERN's Large Hadronic 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 QGP 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 Major Item of Equipment (MIE) Project 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 nearly perfect liquid."

2.0 PROJECT DESCRIPTION AND PERFORMANCE PARAMETERS

The preliminary scope baseline for the sPHENIX MIE is:

- A Time Projection Chamber (TPC), Electromagnetic Calorimeter (EMCAL), a Hadronic Calorimeter (HCal) all covering 2 π 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 (DAQ) system with the capability to readout the TPC, EMCal, 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 nucleus+nucleus (AA), proton+nucleus (pA) and proton+proton (pp) collisions at RHIC.
- Project Management to carry the project scope through to a successful on time and on budget completion.

The preliminary Key Performance Parameters (KPPs) for the sPHENIX MIE are shown in Table 1. The documented threshold KPPs comprise the minimum parameters against which the project's performance will be measured at CD-4. The objective KPPs are the stretch performance parameters that the project will strive for within the CD-2 project scope, cost and schedule performance measurement baseline when established.

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 ≤ 35% 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

3.0 ALTERNATIVE ANALYSIS

The alternatives analysis aims to assess the different approaches to deliver a science program that meets the mission need described in the introduction. The alternative analysis is not intended to distinguish between particular detailed design solutions that utilize similar concepts and technologies. To this end, we have identified the following seven alternatives were identified for evaluation:

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

A more detail description of these seven alternatives can be found in the Analysis of Alternative document found in Appendix A.

3.1 TOTAL LIFE CYCLE COSTS AND BENEFITS

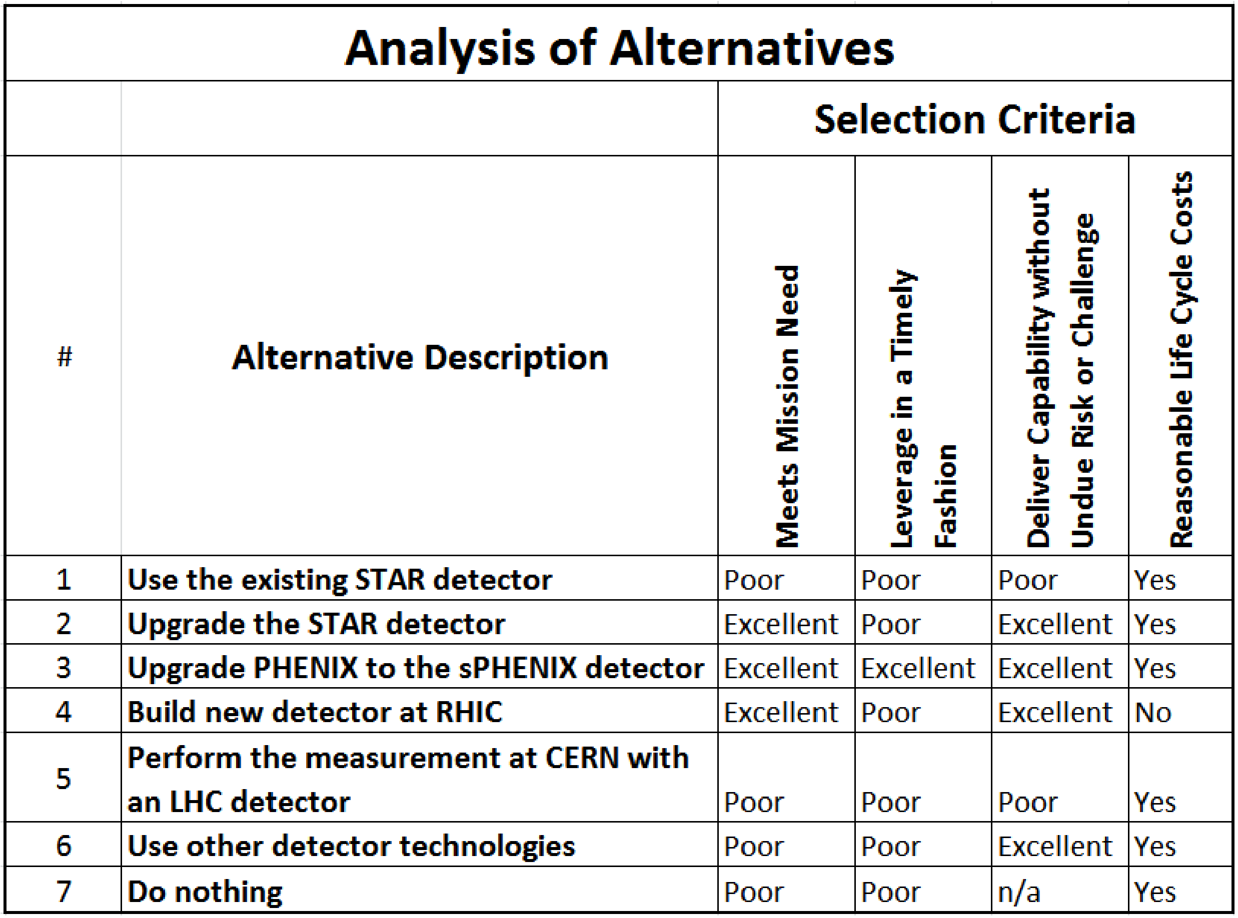
The project life-cycle costs for the fabrication and operation of sPHENIX is estimated to be approximately $86.5-$94.5 million AY. This includes the cost of sPHENIX and fabrication and five years of sPHENIX operations. There is confidence in the estimate for sPHENIX operating costs because the scale and complexity of sPHENIX is known to be very similar to the PHENIX experiment as determined by members of the sPHENIX Management team who were in charge of PHENIX operations throughout the experiment's 16-year operating period. The size of the sPHENIX operating support team, as well as annual consumable and maintenance costs, is estimated to be very similar to that of the PHENIX experiment. The operating cost of $10 million in FY2016 dollars escalated to the sPHENIX operating period of FY2023-FY2027 at 2% escalation per annum results in a five-year sPHENIX operating cost of $60 million AY. The estimate presumes that after five years of operations, the sPHENIX Detector is re-purposed for other research activities.

The capital value of sPHENIX will be added to the capital value of the RHIC facility at the completion of the sPHENIX MIE. It is expected that sPHENIX will operate until the end of the operations of the RHIC facility. At the end of RHIC operations, sPHENIX will either be re-purposed for an application that is commensurate with the future science mission of facilities currently in use by RHIC, such as an Electron Ion Collider, or it will be decommissioned along with the Relativistic Heavy Ion Collider.

4.0 RECOMMENDED ALTERNATIVE

The sPHENIX MIE will be a major upgrade to the PHENIX experiment that will enable the precision characterization of jets produced in AA, pA and pp collisions at RHIC located at BNL. The experiment will also collect a large sample of upsilons with a mass resolution that allows for their separation into three mass states, and the study of their behavior on different distance scales. The sPHENIX MIE provides excellent complimentary to measurements being made at the LHC at CERN, and extends the RHIC physics program in ways that fully exploits RHIC's unique performance capabilities.

Table 2 below 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 (LCC) 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. The table below summarizes the Alternative Analysis results:



Analysis of Alternatives

		Selection Criteria			
#	**Alternative Description**	**Meets Mission Need**	**Leverage in a Timely Fashion**	**Deliver Capability without Undue Risk or Challenge**	**Reasonable Life Cycle Costs**
1	**Use the existing STAR detector**	Poor	Poor	Poor	Yes
2	**Upgrade the STAR detector**	Excellent	Poor	Excellent	Yes
3	**Upgrade PHENIX to the sPHENIX detector**	Excellent	Excellent	Excellent	Yes
4	**Build new detector at RHIC**	Excellent	Poor	Excellent	No
5	**Perform the measurement at CERN with an LHC detector**	Poor	Poor	Poor	Yes
6	**Use other detector technologies**	Poor	Poor	Excellent	Yes
7	**Do nothing**	Poor	Poor	n/a	Yes

Table 2: Summary of Alternative Analysis

The Alternative selected is Alternative 3 Upgrade PHENIX Detector to sPHENIX. A summary of the analysis for the selected alternative is below:

The PHENIX experiment operated in the 1008 complex at RHIC for 16 years. The collision hall and support buildings are well-suited for the installation of a new modern detector. sPHENIX would be an upgrade to the PHENIX experiment, with new capabilities designed specifically to deliver on the Science Mission.

Life Cycle Cost (AY$)

Construction	*$24.2-34.5M*
Operations (5-years)	*$60M*
Decommissioning	*negligible*

Summary

Ability to meet science requirements	*Excellent*
Leverage in a timely fashion	*Excellent*
Deliver capability without undue risk and/or challenges	*Excellent*
Reasonable Life Cycle Cost	*Yes*

Conclusion: Upgrading PHENIX to sPHENIX would enable the experiment to meet Mission need in a timely fashion without undue risk or challenges. It is the least expensive alternative, allows the RHIC Beam Energy Scan program to continue in parallel with sPHENIX construction and delivers on the science mission need years earlier than the alternatives.

5.0 TOTAL PROJECT COST RANGE

For the selected alternative, the preliminary Total Project Cost Range for the DOE-only portion of the project is $24.2 to $34.5 million. The cost range determination is based on several factors including: objective/threshold KPPs, degree of project definition, estimate classification based on DOE Guidelines, review of the project risks in the risk registry, the degree of estimate uncertainty and the alternative analysis for the project. The point estimate for the Total Project Cost to the Level 2 Work Breakdown Structure (WBS) is given in Table 3. The Total Project Cost includes the Total Estimated Cost (TEC) and Other Project Costs (OPC).

		Cost in AY K$				
WBS	**Level 2 WBS Description**	**CDR**	**R&D**	**OPC**	**TEC**	**Total**
1.01	Project Management	$300	$542	$842	$628	$1,470
1.02	Time Projection Chamber	$0	$1,117	$1,117	$2,367	$3,484
1.03	EM Calorimeter	$0	$2,276	$2,276	$3,597	$5,873
1.04	Hadron Calorimeter	$0	$515	$515	$2,949	$3,464
1.05	Calorimeter Electronics	$0	$1,277	$1,277	$3,281	$4,558
1.06	DAQ/Trigger	$0	$313	$313	$1,236	$1,550
1.07	Min Bias Trigger Detector	$0	$82	$82	$51	$132
	Sub-total	$300	$6,123	$6,423	$14,108	$20,531
	Contingency	$0	$0	$0	$6,019	$6,019
	Total Project Cost	**$300**	**$6,123**	**$6,423**	**$20,127**	**$26,550**

Table 3: Cost Estimate for the sPHENIX Detector MIE

6.0 FUNDING PROFILE

The sPHENIX installation and commissioning effort are not part of this MIE scope. The preliminary funding profile is as presented in Table 4.

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 4: Funding Profile for Estimated Total Project Costs

7.0 KEY MILESTONES

Key project milestones are shown in Table 5. CD-4 is planned December 2022, which includes 14 months of schedule contingency.

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 5: Level 1 Milestones

8.0 TAILORING STRATEGY

The sPHENIX MIE has several attributes that justify the use of tailoring principles to simplify and streamline project management and controls and mitigate exposure to schedule and cost risks; including the following:

- The project is an upgrade to an experiment (PHENIX) that has successfully achieved its mission with a series of incremental upgrades largely performed by the same team of collaborators being included in this proposal.

- Advanced designs for some components from other experimental apparatus are being incorporated into the design of the sPHENIX.
- The sPHENIX MIE strategy has been tailored to allow for the early procurement of long lead time items starting in FY2019 after CD-1/CD-3A is approved by DOE. The project will ask for CD-3A approval on specific long lead time items discussed below at the CD-1/3A Review. In addition, due to the advanced nature of both the R&D and detector design, the sPHENIX MIE is proposing a concurrent CD-2/CD-3 review. The project will have a single CD-4 (Approve Project Completion) milestone.

9.0 BUSINESS ACQUISITION AND APPROACH

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, 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.

The Office of Nuclear Physics 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, BSA 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) representing agreements (MOU) and contracts (SOW) between the sPHENIX MIE and the collaborating institutions. These MOUs 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.

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 OHCal. (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 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 EM Cal 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.

10.0 MANAGEMENT STRUCTURE AND APPROACH

The Project Execution Plan (PEP) will be the primary management tool for executing the project. Required changes to cost, scope, or schedule, during execution of the project will be controlled according to the thresholds and processes described in the PEP.

The Associate Director of the Office of Science for Nuclear Physics approved CD-0, and is the Project Management Executive for subsequent Critical Decisions in accordance with DOE Order 413.3B as implemented through the SC Project Decision Matrix.

The sPHENIX MIE Project Manager has the overall responsibility for monitoring the technical design of each sub-system and device and ensuring that the Project's Environment, Safety and Health and Quality Assurance goals are achieved and for monitoring progress against cost and schedule. An Earned Value Management System (EVMS) will be used for performance tracking and evaluation of project performance. The BNL EVMS system has been certified by DOE.

The Federal Project Director (FPD) will monitor and evaluate the project performance against technical, cost, and schedule baselines through monthly project reports, project reviews and

Integrated Project Team (IPT) meetings. The FPD will use the DOE Project Assessment and Reporting System II to deliver project status and assessment information to DOE senior managers and key program stakeholders. Environment, Safety, and Health (ES&H) and quality assurance performance will also be monitored by conducting periodic field observations, using subject matter experts as necessary.

The IPT will provide support to the FPD in management of the sPHENIX MIE. The IPT is organized and led by the FPD, and consists of members from both DOE and BSA. The FPD will work closely with the Federal Program Manager in the SC Office of Nuclear Physics to ensure that the project execution is consistent with program goals and objectives and to ensure the Project Management Executive and appropriate DOE stakeholders are apprised of the project status. This will be accomplished through routine conference calls, site visits, reviews, and other formal and informal communications.

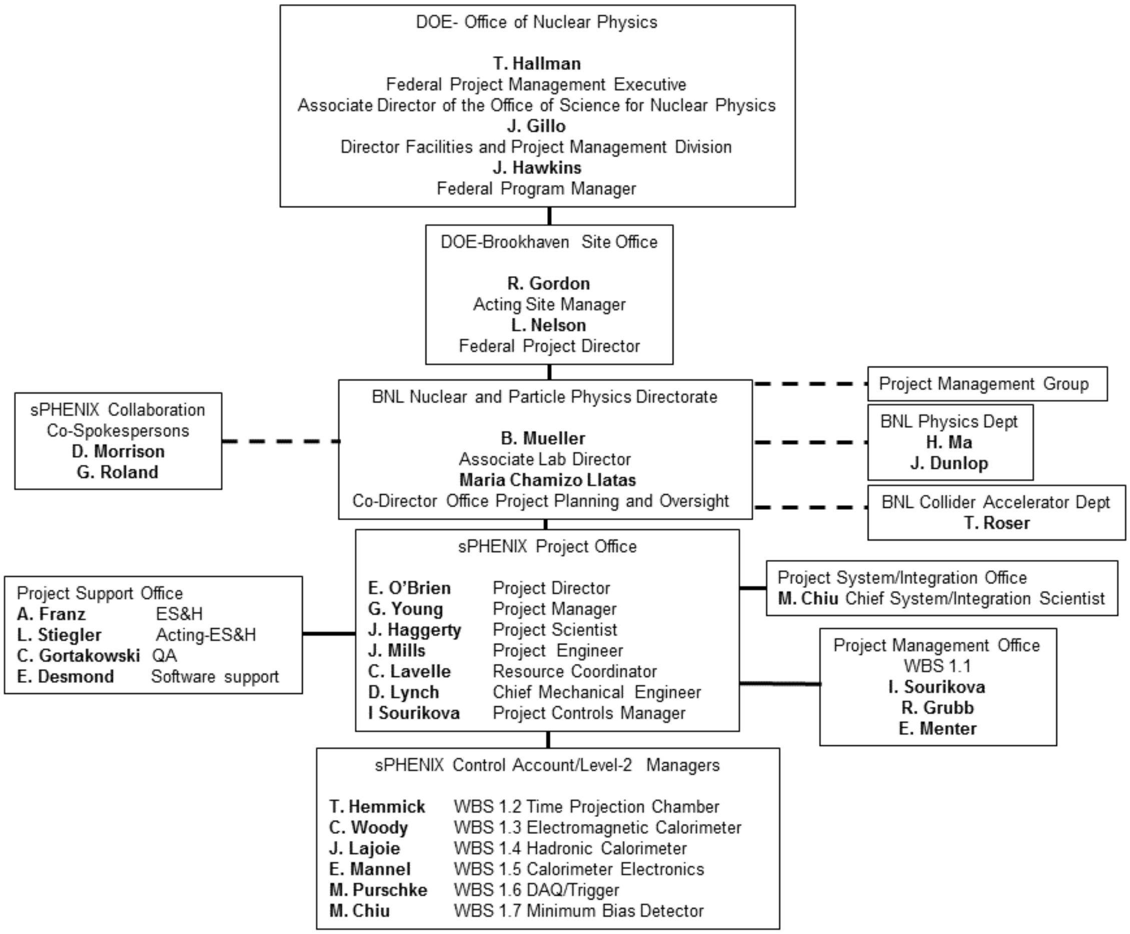


Figure 1: Management structure of the sPHENIX Project

The IPT membership will change as the project progresses from initiation to closeout to ensure the necessary skills are represented to meet project needs. The membership, roles and responsibilities are defined in the Preliminary Project Execution Plan (PPEP).

11.0 RISK ANALYSIS

The management and mitigation of the risks to the project cost, schedule, and technical performance are described in the sPHENIX Risk Management Plan (RMP), and are managed in accordance with the PPEP. The sPHENIX RMP provides a structured and integrated approach for identifying, evaluating, mitigating, and tracking project risks to increase the probability of project and activity success by bringing attention to problem areas early and reducing the amount of costly rework in the future. The management of ES&H risks is handled through the BNL Integrated Safety Management System.

Anticipated risks will be managed at every stage of the project life cycle in order to minimize chances of risks becoming real problems. Abatement strategies, iteratively developed and refined during regular sPHENIX meetings, will be based upon risk category as well as lessons learned from projects of similar scope and complexity. A risk registry will be used as a project-wide risk monitoring tool, while the accountability will be achieved by assigning risk ownership based on the identified risk level. The sPHENIX MIE team together with the Level 2 Managers/ Control Account Managers developed a preliminary risk registry.

APPENDIX A

sPHENIX MIE PROJECT

Conceptual Design: Analysis of Alternatives

at

Brookhaven National Laboratory

Office of Nuclear Physics Office of Science

U.S. Department of Energy

sPHENIX Conceptual Design: Analysis of Alternatives

Conceptual Design: Analysis of Alternatives

1. Project Background and Introduction

The mission of the Office of Science (SC) is to deliver 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 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 institution, to benefit the nation's researchers and national strategic partners.

The 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 Nuclear Physics mission areas under the mandate provided in Public Law 95-91 that established the Department of Energy. The DOE Nuclear Physics program addresses three broad, interrelated scientific thrusts in pursuit of its mission: Quantum Chromodynamics (QCD), Nuclei and Nuclear Astrophysics, and investigations of Fundamental Symmetries using neutrons and nuclei. Over the last two decades, the heavy ion nuclear physics component of the QCD thrust has focused on the discovery and characterization of the Quark Gluon Plasma: a form of matter believed to have last naturally existed in the universe approximately 1 microsecond after the Big Bang. Since the discovery of the QGP at the Brookhaven National Laboratory (BNL) Relativistic Heavy Ion Collider (RHIC) over ten years ago, and sub- sequent confirmation by experiments at CERN's Large Hadronic 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 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 properties.

2. Analysis of Alternatives

The analysis of alternatives aims to assess the different approaches to deliver a science program that meets the mission need described in the introduction. It is not intended to distinguish between particular detailed design solutions that utilize similar concepts and technologies. To this end, we have identified the following 7 alternatives for evaluation:

(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

Each alternative is evaluated in Section 2.2 according to the selection criteria summarized in Section 2.1. The same cost estimating technique was used to evaluate all options. Unless otherwise noted in the text, the estimates were derived from recent cost estimates of similar detectors, scaled appropriately for size and channel count.

2.1 Selection Criteria

Selection criteria for the alternatives are based on the requirements described in the Mission Need Statement, as well as operations requirements, budgetary considerations, and scientific impact. The system must:

a) Meet the science requirements described in 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."
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 first three criteria (a-c) relate to performance and each alternative is individually discussed and ranked as either *poor, good,* or *excellent* in terms of how well it meets these selection criteria. A ranking of poor means the alternative did not meet the selection criterion, *good* means it was partially met, and *excellent* means it was fully met.

The fourth criterion (d) takes into account the life cycle cost, LCC, which is defined as the cost of construction, operations, and decommissioning. The criterion for a *reasonable LCC* is evaluated in the context of the project delivery plus the 5-year operations of the detector for forefront nuclear science, and any decommissioning costs. The alternatives have different capital construction costs, depending on the project scope. The 5-year operating costs are estimated to be the same for the alternatives that involve running at RHIC. The basis for the 5-year operating cost estimate was the cost of operating PHENIX in FY16 escalated to AY$ for detector operations FY23-27. We adopt a process where *reasonable* life cycle costs are evaluated based on the proposed deliverables. A summary ranking of *yes* or *no* is then applied to indicate if selection criterion (d) is met.

A summary table is provided for each alternative and a comparison of all alternatives is given at the end.

2.2 Discussion of Analysis of Alternatives

Alternative (1): Use the existing STAR Detector

The STAR detector is entering its 18th year of running this year. It has a limited capability to measure hadronic jets, poor mass resolution of the Upsilon states due to a weak magnetic field and a slow data acquisition system that enables the detector to take less than 10% of the full RHIC luminosity in Au+Au collisions. This alternative would have STAR attempt to accomplish the Science Mission without upgrade. It would pursue the Mission through continued running at RHIC.

Life Cycle Cost (AY$)

Construction	*$0M*
Operations (5-years)	*$60M*
Decommissioning	*negligible*

Summary

Ability to meet science requirements	*Poor*
Leverage in a timely fashion	*Poor*
Deliver capability without undue risk and/or challenges	*Poor*
Reasonable Life Cycle Cost	*No*

Conclusion: The STAR detector would be unable to deliver on a Physics program that satisfied Mission Need. The STAR detector has a Data Acquisition System that operates at an order of magnitude slower than the necessary rate. This limits the statistics that the experiment can archive which in turn limits the experiment's sensitivity. It has a magnetic field that is approximately 3X weaker than what is required which means that it cannot obtain the mass resolution to adequately separate mass peaks of the Upsilon. It does not have a hadronic calorimeter which limits its ability to extract jets from the underlying event with the necessary sensitivity for the jet measurement. It has an EMCal that lacks the needed transverse segmentation by a factor of 10 to spot single photons in the multiplicity environment of a Au+Au collision. The Life Cycle Costs are a poor investment for an option that cannot deliver on mission need.

Alternative (2): Upgrade the STAR Detector

The STAR detector could be upgraded to deliver the capabilities of a high rate experiment to measure jets and upsilons at RHIC. An upgraded STAR would require the replacement of the STAR magnet, Time Projection Chamber, and Electromagnetic Calorimeter (EMCal). The upgraded detector would need a new high-field super conducting magnet (SC-magnet), a tracker that can be read out at high rates, a more finely segmented electromagnetic calorimeter (EMCal), a hadronic calorimeter (HCal) and a faster Data Acquisition system (DAQ) to deliver on the Science Mission. One could build a detector with those capabilities in the STAR collision hall. Based on cost estimates for similar detectors the STAR upgrade would cost $35-45M. It would require an early stop to the STAR Beam Energy Scan program, or a delay in the start of the Upgraded STAR detector construction.

Life Cycle Cost (AY$)

Construction	*$36.5-45.5M*
Operations (5-years)	*$60M*
Decommissioning	*negligible*

Summary

Ability to meet science requirements	*Excellent*
Leverage in a timely fashion	*Poor*
Deliver capability without undue risk and/or challenges	*Excellent*
Reasonable Life Cycle Cost	*Yes*

Conclusion: An upgrade to the STAR detector that added a new magnet, tracker, EMCal, HCal and DAQ is estimated to cost in the range $35–45M. It would have the capability to deliver on the Science Mission. However, the construction of an upgraded STAR detector would not start until it had completed its beam energy scan currently in the BNL plan to end in 2021. To adopt this approach, one would have to either forego the Beam Energy scan which is considered a high priority in the most recent NSAC long range plan, or delay the start of the "jet and upsilon" physics program at STAR by 3-4 years. This implies the continuation of RHIC Operations for an additional 3-4 years. Upgrading STAR as described would deliver the Science Mission but result in either a 3-4-year delay in the start of the "jet and upsilon" program, or an early termination of the Beam Energy Scan which is considered important physics.

Alternative (3): Upgrade PHENIX to the sPHENIX Detector

The PHENIX experiment operated in the 1008 complex at RHIC for 16 years. The collision hall and support buildings are well-suited for the installation of a new modern detector. The sPHENIX MIE would be an upgrade to the PHENIX experiment, with new capabilities designed specifically to deliver on the Science Mission.

Life Cycle Cost (AY$)

Construction	*$24.2-34.5M*
Operations (5-years)	*$60M*
Decommissioning	*negligible*

Summary

Ability to meet science requirements	*Excellent*
Leverage in a timely fashion	*Excellent*
Deliver capability without undue risk and/or challenges	*Excellent*
Reasonable Life Cycle Cost	*Yes*

Conclusion: Upgrading PHENIX to sPHENIX would enable the experiment to meet Mission need in a timely fashion without undue risk or challenges. It is the least expensive alternative, allows the RHIC Beam Energy Scan program to continue in parallel with sPHENIX construction and delivers on the science mission need years earlier than the alternatives.

Alternative (4): Build New Detector at RHIC in a new Interaction Region

The experimental areas where the PHENIX and STAR experiments operate have had infrastructure and support systems installed in those facilities over the past twenty years. One could consider building a new detector in a new collision hall. The available hall at RHIC would be the 1012 complex. It can accommodate a large detector but is a “green field” and would require significant work before it could support a major detector with the capabilities to carry out the jet and upsilon physics program. Studies have estimated that preparing a new detector hall at RHIC would cost $35M due to the large infrastructure investment required.

Life Cycle Cost (AY$)

Construction	*$70-80M*
Operations (5-years)	*$60M*
Decommissioning	*negligible*

Summary

Ability to meet science requirements	*Excellent*
Leverage in a timely fashion	*Poor*
Deliver capability without undue risk and/or challenges	*Excellent*
Reasonable Life Cycle Cost	*No*

Conclusion: A new detector that has the capabilities to deliver on the jet and heavy flavor physics program described in the 2015 NSAC LRP built in a new Interaction Region (IR) at RHIC would be feasible and would also have the capabilities to deliver on the Mission Need science. However, it has been estimated that to configure a new IR at RHIC with all the experimental support services available at either Building 1008 (PHENIX) or 1006 (STAR) would cost a minimum of $35M and take 3-4 years to design and prepare based on the experience outfitting the existing PHENIX and STAR halls. If one were to choose this option one would expect that it would cost an additional $35M to prepare the new experimental area and cause a delay to the science program by 3-4 years.

Alternative (5): Perform the Measurement at CERN with an LHC Detector

The LHC is a heavy ion collider accelerator located at CERN in Geneva, Switzerland. It has three very capable experiments that carry-out heavy ion physics research programs: ALICE, ATLAS and CMS. The LHC collider is optimized to operate at much higher collision energy than RHIC.

Life Cycle Cost (AY$)

Construction	*$0M*
Operations (5-years)	*$60M*
Decommissioning	*negligible*

Summary

Ability to meet science requirements	*Poor*
Leverage in a time fashion	*Poor*
Deliver capability without undue risk and/or challenges	*Poor*
Reasonable Life Cycle Cost	*No*

Conclusion: The option of completing the scientific mission at an LHC experiment is not viable primarily because the measurement to be done to fulfill the Science Mission have to be made near the Quark Gluon Plasma phase transition energy. In other words, the measurements need to be made at the lower energies available at RHIC that are not possible for the LHC. The sPHENIX proposal highlights the complementarity of measurements at the lower and higher collision energies available at RHIC and the LHC, respectively, as a way of determining the temperature dependence of key QGP transport coefficients. There are several reasons why lowering the energy of the LHC is not a feasible way to produce collisions with a lower initial temperature. For a given accelerator, the luminosity typically varies as L ~ E2, so lowering the energy of the LHC by a factor of 30 to match the top energy of RHIC would reduce the luminosity of the LHC heavy-ion beams by two to three orders of magnitude. This would result in needing an impractically long physics program lasting several decades to accumulate the necessary statistics. In addition, the beam control systems of the LHC are designed for conditions of high luminosity—manipulating and monitoring a beam of such low intensity in the LHC would certainly require significant commissioning time, if it is even possible.

A different possible way to control the initial temperature would be to collide lighter ions in the LHC, although this severely limits the size of the plasma produced. The heavy-ion program is allotted only several weeks per year for running time, having to compete with the LHC's main program of high energy proton-proton collisions. The LHC calendar through the 2020s is already planned, with runs to accumulate high statistics in Pb-Pb and p-Pb collisions, but there is no running time foreseen for lighter ion collisions.

Alternative (6): Use Other Detector Technologies

Potential alternate technologies were studied to determine whether any could be employed by sPHENIX to make the project less expensive, timelier or more technologically robust while still meeting Mission Need.

Life Cycle Cost (AY$)

Construction	*$103.5-111.5M*
Operations (5-years)	*$60M*
Decommissioning	*negligible*

Summary

Ability to meet science requirements	*Poor*
Leverage in a timely fashion	*Poor*
Deliver capability without undue risk and/or challenges	*Excellent*
Reasonable Life Cycle Cost	*No*

The Upsilon program requires a high field magnet in order to fully resolve the three mass states and to separately measure their suppression in heavy-ion collisions. This effectively rules out a warm magnet and drives the design to a superconducting solenoid. The early sPHENIX detector concept anticipated a custom built 2 tesla superconducting magnet with an open bore of 1.8 m. Current experience with building research magnets like this is fraught with technical, schedule and cost risks. We obtained a quotation from Ansaldo, the company that built the BaBar superconducting solenoid, for a magnet of such a design. A review at the time resulted in the assignment of 100% contingency to the cost estimate. This would have consumed several million dollars of the budget, required the identification of superconducting magnet expertise not already associated with the collaboration, and would have left the project with a high risk, long lead time item. We have chosen to reuse the former BaBar magnet. The excellent BaBar magnet has a known track record of performance and is a lower risk way to provide the necessary magnetic field for the experiment. This option resulted in a savings of $20M in direct costs plus a high estimate uncertainty in the cost.

Magnet:

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Tracking System:

A number of tracking technologies were considered for sPHENIX. A tracking system consisting entirely of silicon sensors was initially attractive due to its speed and excellent space point position resolution. A silicon detector is able to easily distinguish hits from individual crossings, making it straightforward to trigger on events of interest and reconstruct events. The position resolution insures good momentum measurement at high pT. In addition, a number of sPHENIX collaborating institutions have considerable experience with strip and pixel detectors.

However, a silicon detector capable of resolving the Upsilon states would necessarily have one or more layers at a radius of 60–90 cm, which would require several square meters of silicon sensors. The cost of the sensors, electronics, and support structure for such a large silicon tracker was estimated to be $30M in direct costs which can be compared to the cost of the Time Projection Chamber in sPHENIX which is in the range of $3M in direct costs. In addition, the momentum resolution at low pT is largely determined by multiple scattering, and minimizing the amount of material in the sensors and the electronics and cooling in close proximity is a major technical challenge.

Electromagnetic Calorimeter:

A number of alternative designs for the electromagnetic calorimeter have been considered.

The BaBar experiment had a CsI electromagnetic calorimeter which is available to a new experiment. Clearly, it is a good match mechanically to the BaBar solenoid, occupying radial space from about 90 cm to the inner radius of the cryostat, but its segmentation, Moliere radius, and time resolution are not well suited to RHIC heavy ion operation. The Moliere radius of the CsI (Tl) is 3.8 cm compared to about 2.2 cm of the proposed calorimeter, limiting the segmentation possible at the radius that the electromagnetic calorimeter could be deployed, and the segmentation reflects that, with the barrel divided into 48 rings of 120 crystals, compared to the proposed rings of 256 calorimeter elements. CsI (Tl) is a relatively slow scintillator, with an average decay time of about 1ms, which would effectively integrate over 10 or more RHIC crossings. Despite the attractiveness of redeploying an elegantly engineered and executed detector, it is not suitable for use at RHIC as part of a barrel calorimeter. A calorimeter with such a slow time response would not work in the particle environment at RHIC.

Other crystal calorimeter options are attractive, in particular PbWO4, as used in the CMS electromagnetic calorimeter. Lead tungstate crystals are fast, have a short radiation length (8.9 mm), and can give excellent energy resolution. If they could be produced in a timely fashion at a reasonable cost, they would be satisfactory. However, there are very few sources of crystals in the world, with none currently growing acceptable crystals, and the cost of growing them is high, resulting in crystal costs of \$5/cc to \$10/cc, compared to a material cost for the SPACAL of \$1.50/cc. A lead tungstate calorimeter with the same coverage would have costs in the range of \$15 to \$30M more in direct costs. The CDF and D0 experiments were surveyed for possible calorimeter components. Aside from the logistical challenges of extracting the desired components, the size and mechanics do not appear to be practical to redeploy either inside or outside the BaBar solenoid.

A lead-scintillator “shashlik” calorimeter similar in design to the PHENIX and ALICE calorimeters was considered. The tooling for the construction of the ALICE calorimeter is still available, and the performance of these designs has been extremely satisfactory both in PHENIX and ALICE. Depending on the sampling fraction, the Moliere radius can be tuned to give adequate segmentation, but with lead absorber, fitting a depth of at least 18 radiation lengths requires a radial extent that precludes any part of the hadronic calorimeter (or second longitudinal segment of the electromagnetic calorimeter) inside the radius of the magnet cryostat. Use of tungsten absorber in a” shashlik” design was investigated. This would reduce the Moliere radius and make the design very competitive with a tungsten SPACAL. However, due to the difficulties of working with metallic tungsten and the number of holes needed in the absorber plates, this solution would require considerable development, and a potentially lengthy process of prototyping and testing. A tungsten scintillating fiber” accordion” calorimeter was also considered, which would have a similar Moliere radius, radiation length and sampling fraction as the W/Sci-Fi SPACAL. A prototype calorimeter of this type was in fact built and tested. However, due to the difficulty of forming the tungsten accordion plates and controlling their tolerances at reasonable cost, this option was also rejected in favor of the W/Sci-Fi SPACAL. In summary a lead-scintillator “shashlik” calorimeter would have been less expensive, estimated saving were $2-3M, but they are too large to fit inside the former BaBar magnet. A tungsten “shashlik” or tungsten “accordion” calorimeter was considered but there was no obvious costs savings for a significantly less developed technology. There would have been considerably higher technical risk with no associated savings.

Hadronic Calorimeters:

A number of alternative designs for the HCal have been considered. Two obvious avenues that have been explored are to re-purpose a calorimeter retired from another experiment, or to copy an existing design from another experiment. A site visit to Fermilab to consider the CDF and D0 calorimeters took place in February 2012. The D0 liquid Argon calorimeter would be very complicated to extract from the collision hall, and requires a sophisticated cryogenic system, which would have to be moved or duplicated. We were told that it would cost a minimum of $2M to extract the D0 calorimeter and even after that the physical dimensions of the calorimeter would not a good match to the BaBar solenoid. The CDF calorimeter is physically substantially larger than sPHENIX, and mechanical rework would be necessary on the calorimeter modules. Neither were a practical alternative.

For a new hadronic calorimeter, we studied a variety of technologies and concluded that a steel-scintillator based technology is the cheapest solution that can both double as a flux return and provide the hadronic energy resolution that the experiment requires. Engineering studies showed that the cost of steel-scintillator HCal’s were similar regardless of its basic geometry. The HCal cost is driven by the cost of machined steel, and scintillator tiles.

In summary we have done a board survey of alternate technologies to be used in sPHENIX. We have chosen the least expensive technical solution in each case that allows for the completion of the Scientific Mission. Alternate technologies increased the sPHENIX costs up to a maximum increase of $77M in direct costs.

Alternative (7): Do Nothing

Life Cycle Cost (AY$)

Construction	*N/A*
Operations (5-years)	*$0M*
Decommissioning	*negligible*

Summary

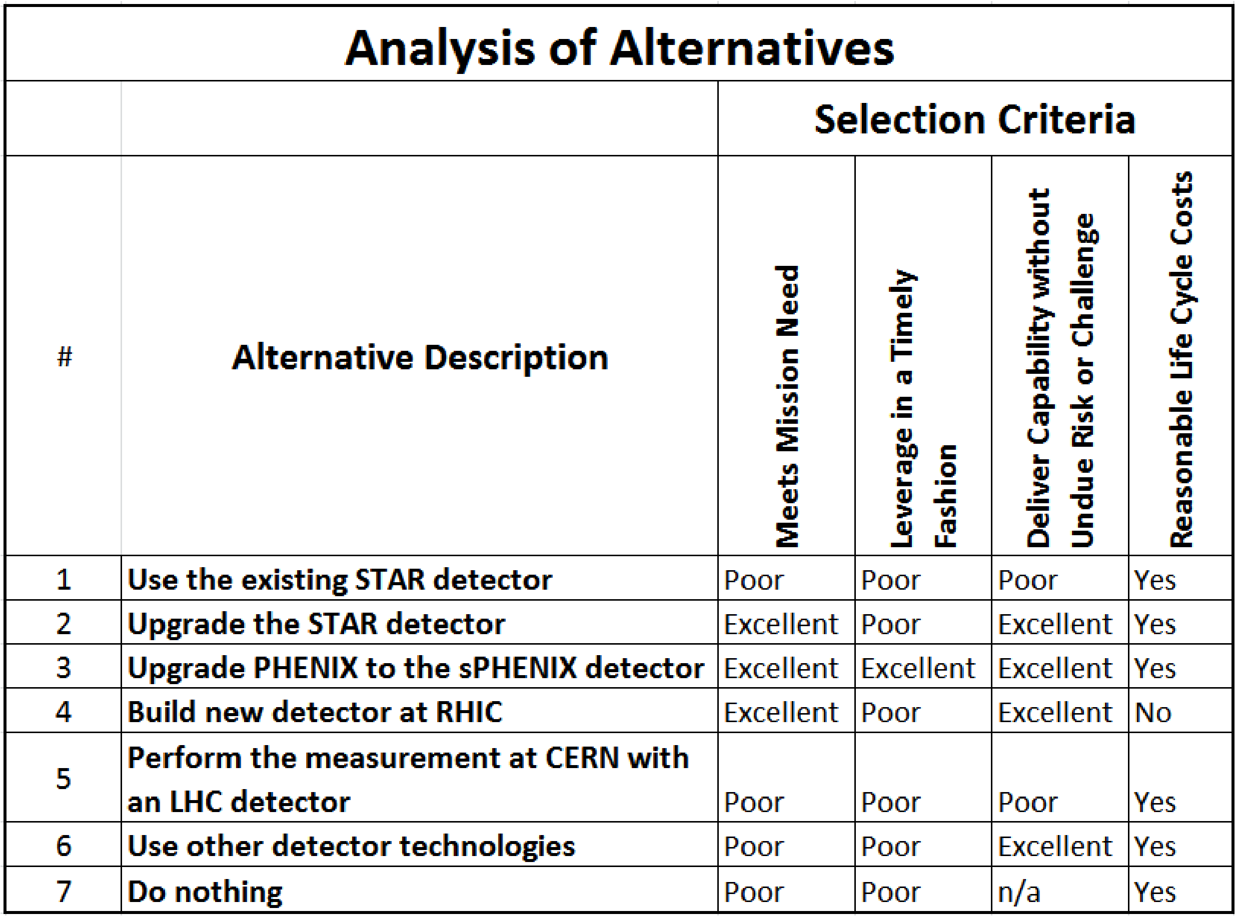
Ability to meet science requirements	*Poor*
Leverage in a timely fashion	*Poor*
Deliver capability without undue risk and/or challenges	*N/A*
Reasonable Life Cycle Cost	*No*

Conclusion: It is not possible to accomplish the science mission by doing nothing.

3. Analysis of Alternatives Summary and Recommendation

Table I 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 (LCC) 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.

Table I: Summary of alternative analysis



Analysis of Alternatives

		Selection Criteria			
#	**Alternative Description**	**Meets Mission Need**	**Leverage in a Timely Fashion**	**Deliver Capability without Undue Risk or Challenge**	**Reasonable Life Cycle Costs**
1	**Use the existing STAR detector**	Poor	Poor	Poor	Yes
2	**Upgrade the STAR detector**	Excellent	Poor	Excellent	Yes
3	**Upgrade PHENIX to the sPHENIX detector**	Excellent	Excellent	Excellent	Yes
4	**Build new detector at RHIC**	Excellent	Poor	Excellent	No
5	**Perform the measurement at CERN with an LHC detector**	Poor	Poor	Poor	Yes
6	**Use other detector technologies**	Poor	Poor	Excellent	Yes
7	**Do nothing**	Poor	Poor	n/a	Yes