sPHENIX Response to PD-2/3 Report August 7, 2019

Brookhaven National Laboratory organized a Project Decision-2/3 (PD-2/3) review of the sPHENIX Project that was held on May 28-30, 2019 at BNL. The review charge is included in the appendix of this document. The final PD-2/3 review report has been provided to the committee as a separate document. The final report of the review committee contained six recommendations that are all addressed in this document.

sPHENIX PD2-3 Final Report Recommendations:

Project Management

1. There should be a dedicated ES&H Manager for the project.
2. ES&H should periodically visit universities and/or collaborators, possible look at Office of Quality Management frequency of visits.
3. The committee recommends PD-2/3 after a clean-up, review and status of the project schedule, cost estimate and risk register.

Time Projection Chamber (TPC)

4. The review committee recommends PD-2 for the TPC. Before PD-3, however, the TPC group needs to establish credible production readiness. The review committee is convinced that the TPC Team is very capable; is very close to proving production readiness and that an appropriate focus in the coming weeks could see it done. To this end, we recommend that this be accomplished using their first set of pre-production chambers to simultaneously study the actual Ion Back Flow (IBF), energy resolution and discharge stability for their proposed gas mixture as a function of possible operating point settings for the full range of Gas Electron Multiplier (GEM) voltages and transfer fields. This is to be done with the front mesh in place (if that continues as a design option) to confirm that an operating point exists that meets all sPHENIX requirements with their proposed gas mixture. Once the above is completed to the satisfaction of the sPHENIX Project Director and reported to the Review Committee, the TPC can proceed to PD-3.
5. As indicated in last year's review, all components on the TPC Front End Electronics (FEE) board needs to be radiation-qualified; this has been largely achieved but some tests remain. Demonstrate the performance of (two) full TPC FEE boards with SAMPA V4 Application Specific Integrated Circuits (ASICs) versus dose up to a Total Integrated Dose (TID) of at least 100 krad. Once available, repeat this demonstration using full TPC FEE boards with SAMPA V5 ASICs. The Committee then recommends proceeding to PD-2/3.

EM Calorimeter

6. Re-evaluate the contingency associated with large procurements such as the tungsten (W) powder, in view of the recent cost increase in this material and possible pending tariff situation. Once the above is satisfactorily completed, to the satisfaction of the sPHENIX Project Director and reported to the Review Committee, the Electron Magnetic Calorimeter (EMCal) can proceed to PD-2/3.

Response to Recommendation 1:

“There should be a dedicated ES&H Manager for the project.”

The sPHENIX Environmental, Safety, and Health (ES&H) Coordinator manages ES&H for sPHENIX. The person manages and directs the global safety management system for the sPHENIX project and is assigned as a permanent member of the project team. The ES&H Coordinator reports directly to the sPHENIX Project Director, as shown in the DOE-approved sPHENIX Organization chart, and takes part in all project safety, progress, design, and preproduction reviews as appropriate. The ES&H Coordinator also interacts and coordinates with safety personnel in the Physics Department, Collider- Accelerator Department and any other location on BNL site where sPHENIX work is ongoing.

The effort required by the ES&H Coordinator has been integrated into the Resource-Loaded Schedule (RLS) for sPHENIX. The ES&H Coordinator effort appearing in the RLS has been thoroughly evaluated and deemed adequate to provide the necessary support not only for the scheduled sPHENIX activities but also to support any unanticipated risks that would require their attention.

Additional responsibilities of the sPHENIX ES&H Coordinator includes ensuring that acceptable safety practices are being carried-out at sPHENIX collaboration sites where fabrication of sPHENIX project components is taking place by visiting those sites and meeting with local safety and work coordinators. The ES&H Coordinator works with the sPHENIX Management team to ensure that all relevant sPHENIX activities adhere to all safety, health and environmental practices as specified in BNL Standards-Based Management System (SBMS).

Response to Recommendation 2:

“ES&H should periodically visit universities and/or collaborators, possible look at Office of Quality Management frequency of visits.”

Fabrication work on the sPHENIX Major Item of Equipment (MIE) is taking place at BNL, Stony Brook University (SBU), University of Illinois –Urbana-Champaign (UIUC), Georgia State University (GSU), and commercial vendors. SBU is building the mechanics for the Time Projection Chamber, UIUC is building the blocks for the EM Calorimeter, and GSU is testing approximately 6400 scintillating tiles for the Hadron Calorimeter (HCal). SBU has been visited in the spring of 2019 by a team of BNL-sPHENIX engineers, the sPHENIX ES&H Coordinator and the sPHENIX Quality Assurance (QA) Coordinator. The sPHENIX team toured the TPC mechanics production facility, met with SBU personnel responsible for ES&H and QA and observed the facility in action. A BNL-sPHENIX team that includes the ES&H and QA Coordinators have scheduled a visit to tour and observe the UIUC EMCal block fabrication facility the week of August 26. The UIUC visit will include observation of EMCal block production, and meetings between the BNL-sPHENIX team and UIUC personnel responsible for ES&H and QA at the block fabrication facility. The GSU scintillating tile testing facility will not have any significant activity underway until November 2019. The BNL-sPHENIX team will schedule a visit to the GSU facility once work is underway there later this year to observe the tile testing activities and meet with local GSU personnel responsible for ES&H and QA at that facility.

Response to Recommendation 3:

“The committee recommends PD-2/3 after a clean-up, review and status of the project schedule, cost estimate and risk register.”

The Project team has revised the proposed sPHENIX cost and schedule baseline plan since the PD-2/3 review at the end of May 2019. Comments from the PD-2/3 review team have been incorporated into the sPHENIX Project Cost and Schedule Baseline as appropriate. The PD-2/3 recommendation to review and status the project schedule, cost estimate and risk register is complete. The actions taken to address this recommendation are as follows:

1. Made minor corrections to labor hours planned in WBS 1.2 (TPC).
2. Expanded the schedule to include activities leading up to Review milestones.
3. Updated out of date vendor quotes.
4. Reviewed and revised the Risk Registry where appropriate.
5. Reviewed and revised the estimate uncertainty assigned to activities where appropriate.
6. Reviewed and revised the schedule logic.
7. Statused the schedule through May 31.
8. Set the sPHENIX project cost/schedule baseline as of June 1.
9. Validated the cost contingency percentage based on work remaining.
10. Confirmed that the schedule contingency of 14 months is valid.
11. Confirmed the early finish date of October 2021.

Each of the suggestions by the review committee has been assessed with corrections and changes being incorporated into the project baseline where appropriate. All modifications were documented by the Project team. The Project Management Plan (PMP) has been updated to reflect the revised baseline by Control Account (See Figure 1 sPHENIX Cost/Schedule Baseline). The results of setting the baseline have been finalized in the cost/schedule baseline Cost Performance Report (See Figure 4 initial CPR dated 5/31/2019).

The most important project parameters remain unchanged, or improved from those shown at the PD-2/3 review. The TPC remains at 27.0 M AY$. The Early Finish date remains at October

2021 and the cost contingency percentage has improved from the 26% shown at the PD-2/3 review to 27.5% based on the Estimate to Complete (ETC) as of June 1, 2019. The baseline has been set as of June 1, 2019 and the tailored EVM reporting as outlined in the PD-2/3 Review will be conducted monthly.

There were several minor flaws discovered in the estimate and schedule (i.e. project review activities in WBS 1.02 & resources on short duration activities) that were cleaned up before the baseline was established.

Changes to sPHENIX Cost/Schedule Baseline Implemented to Finalize and Set the Baseline as of June 1, 2019

1. The review committee identified cases of a high number of hours on activities with short duration in WBS 1.2 during Cost/Schedule Drilldown

The few instances of high hour/short duration activities were reviewed by both PM and the appropriate CAM. Errors in the estimate for the number of hours were identified and the error was corrected in the baseline P6 file. The cause of the error was determined, and the number of hours corrected. The error happened during a reorganization of the logic associated with review preparation when effort associated with long duration design tasks got inadvertently assigned to short duration "review preparation".

A review was made of hours/day/labor resources for all activities to find and correct the few other cases where personnel were over-allocated.

A few procurement strings still retain a large number of hours, for example for procurements for the FELIX boards used in the digital part of the TPC readout chain. However, these steps also have long durations of 15 weeks, because there are large numbers of small orders needed to companies producing specialized high-value electronics components in order to assemble the eclectic set of components required for these high-performance electronics boards.

2. Review activities that should precede milestones in the schedule for reviews identified during Cost/Schedule Drilldown

These activities were reviewed, and it was determined that the needed milestones existed, but a number lacked resources and/or time to conduct the review. The activities were revised to show at minimum 1-day durations (if they had been entered as zero-duration milestones) and labor was added as appropriate for University staff and Physics staff to conduct the review. A few examples are:

- the PDR (activity S109200), FDR (activity S112300), safety review (activity S112200) and PRR (activity S112600) for the TPC field cage, all of which needed resources; the safety and Procurement Readiness reviews also needed non-zero duration;

- the FDR and PRR for the initial EMCal modules (activity S183801), which needed resources and non-zero durations;

- the PRR for the assembly of the main production sequence of OHCal sectors (activity S209701), which needed resources and non-zero duration.

3. Some Vendor Quotes needed to be updated in WBS 1.2
   Checked all vendor quotes in BOE, all out of date quotes have been updated. The production quotes for the SAMPA chip development and prototyping work, and then for the main SAMPA production run were reviewed and updated and the corresponding section of the WBS (1.02.05.03) revised. Quotes and the WBS were updated for the TPC central membrane (activity S107900), TPC FEE production boards (S143200), TPC data fibers (S145750), the cooling system for the production EMCal sectors (S196100), the pre-production 7-crate digitizer system for the calorimeters (S251000, S251100, S251200), and the production shaper/discriminator boards for the Min-Bias Detector (S273600). Finally, the contract award was made for the production order of scintillating tiles for the OHCal, and the WBS updated (S208300) to reflect the contract award value.

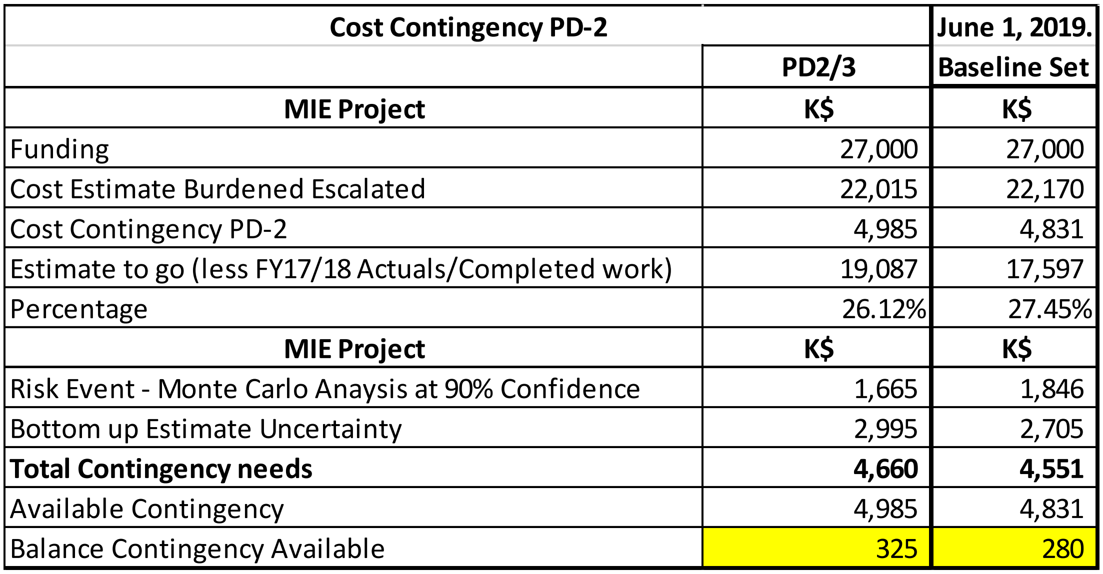
4. The Project Schedule has been frozen. The schedule contingency remains at 14 months. The early completion date is unchanged.
   The Project schedule has been statused as of June 1 and the baseline has been established. The project early completion date is remains at October 2021 with 14 months of schedule contingency. The early finish date and schedule contingency remain unchanged from the PD-2/3 Review. (See Critical Path, Figure 5)
   The PMP milestone dates have been updated. See Milestone Chart Figure 6.

The statusing to June 1, 2019 and baselining process resulted in the following changes to the Level 2 Control Accounts from the numbers presented at the May PD-2/3 review:

Cost Baseline K$				
WBS	**Level 2 WBS Description**	**PD-2/3**	**Baseline**	**Delta/Change**
1.01	Project Management	$2,314	$1,952	-362
1.02	Time Projection Chamber	$4,296	$4,170	-126
1.03	EM Calorimeter	$5,162	$5,196	34
1.04	Hadron Calorimeter	$3,653	$4,069	416
1.05	Calorimeter Electronics	$5,261	$5,373	112
1.06	DAQ/Trigger	$1,203	$1,240	37
1.07	Min Bias Trigger Detector	$126	$170	44
	Performance Measurement Baseline	**$22,015**	**$22,169**	**154**
	Contingency	$4,985	$4,831	-154
	Total Project Cost	**$27,000**	**$27,000**	**0**

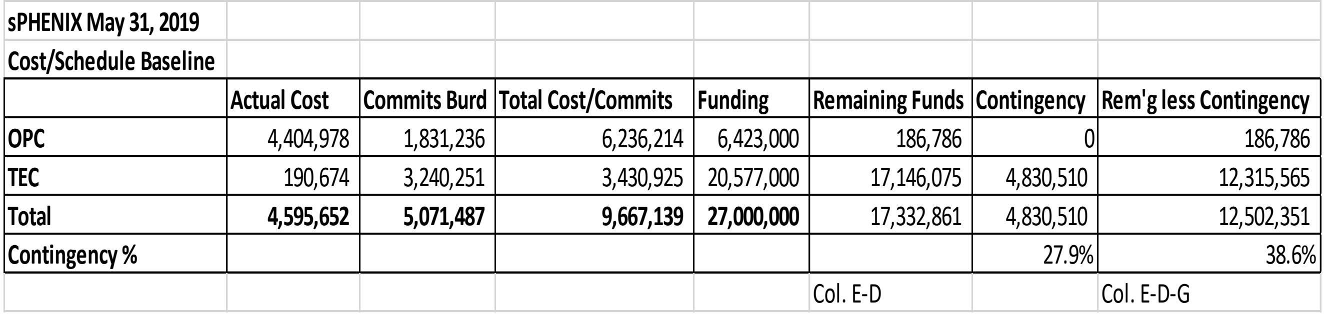
Figure 1: Cost Baseline shown at WBS Level-2. Comparison between the Cost shown at the PD-2/3 review and the proposed baseline.

The cost contingency in the baseline is $4,831k which is a $154K reduction from the cost contingency number of $4,985k shown at the PD-2/3 review. The remaining work in the baseline is costed at $17,597K which is a $1,490k reduction from the remaining work of $19,087 shown at the PD-2/3 review. The contingency on work remaining is 27.5 % in the baseline (See Figure 2). The percentage of contingency for the remaining unobligated work to go is 38.6% (See Figure 3). The baseline Total Project Cost of $27.0 M is unchanged from the Total Project Cost presented at the PD-2/3 Review.



Cost Contingency PD-2		**June 1, 2019.**
	PD2/3	**Baseline Set**
MIE Project	**K$**	**K$**
Funding	27,000	27,000
Cost Estimate Burdened Escalated	22,015	22,170
Cost Contingency PD-2	4,985	4,831
Estimate to go (less FY17/18 Actuals/Completed work)	19,087	17,597
Percentage	26.12%	27.45%
MIE Project	**K$**	**K$**
Risk Event - Monte Carlo Anaysis at 90% Confidence	1,665	1,846
Bottom up Estimate Uncertainty	2,995	2,705
Total Contingency needs	**4,660**	**4,551**
Available Contingency	4,985	4,831
Balance Contingency Available	325	280

Figure 2: Cost Contingency difference between PD-2/3 and the baseline proposal.



sPHENIX May 31, 2019							
Cost/Schedule Baseline							
	Actual Cost	**Commits Burd**	**Total Cost/Commits**	**Funding**	**Remaining Funds**	**Contingency**	**Rem'g less Contingency**
OPC	4,404,978	1,831,236	6,236,214	6,423,000	186,786	0	186,786
TEC	190,674	3,240,251	3,430,925	20,577,000	17,146,075	4,830,510	12,315,565
Total	**4,595,652**	**5,071,487**	**9,667,139**	**27,000,000**	17,332,861	4,830,510	12,502,351
Contingency %						27.9%	38.6%
					Col. E-D		Col. E-D-G

Figure 3: Contingency Analysis as % Cost/Commits (Burdened)

As part of the baselining process, the project team scrubbed the estimate uncertainty (EU) keeping in mind comments from the technical subcommittees. The EU had last been reviewed and updated just prior to the PD-2/3 review. There were four areas of focus for the EU reevaluation: the SAMPA chip development and production (TPC), the GEM foil production (TPC), the Inner HCal support structure (HCal), and the cost of custom electronics parts (TPC & Calorimeter electronics), notably complex FPGAs, for the TPC and calorimeter electronics.

The SAMPA WBS (1.02.05.03) was re-organized and cost reduced based on completed work over the spring at the vendor (U. Sao Paulo). The estimate uncertainty was left unchanged for the future work because the design basis and quotes from the chip vendor remain unchanged.

The GEM foil cost was confirmed by the CERN laboratory where they will be built, and the laboratory confirmed they stand ready to perform the requested work for sPHENIX, thus this estimate and its uncertainty were left unchanged.

The inner HCal support structure Basis of Estimate (BOE) document (activity 199300) did include a vendor quote, which would normally have an estimate uncertainty of 10% assigned (category M3). However, the stability of this mechanical structure was under further analysis at the time of preparation for the PD-2/3 review, and it was decided to use instead M5, professional judgement, 40%, to reflect this status. Subsequent to the review, this further analysis has shown that welding in addition to the proposed bolting method of attachment for this structure is needed to provide adequate stability and resistance to flexing. This will add some 10-20% to the estimated cost. Therefore, the EU has been kept at M5, 40%, for this activity.

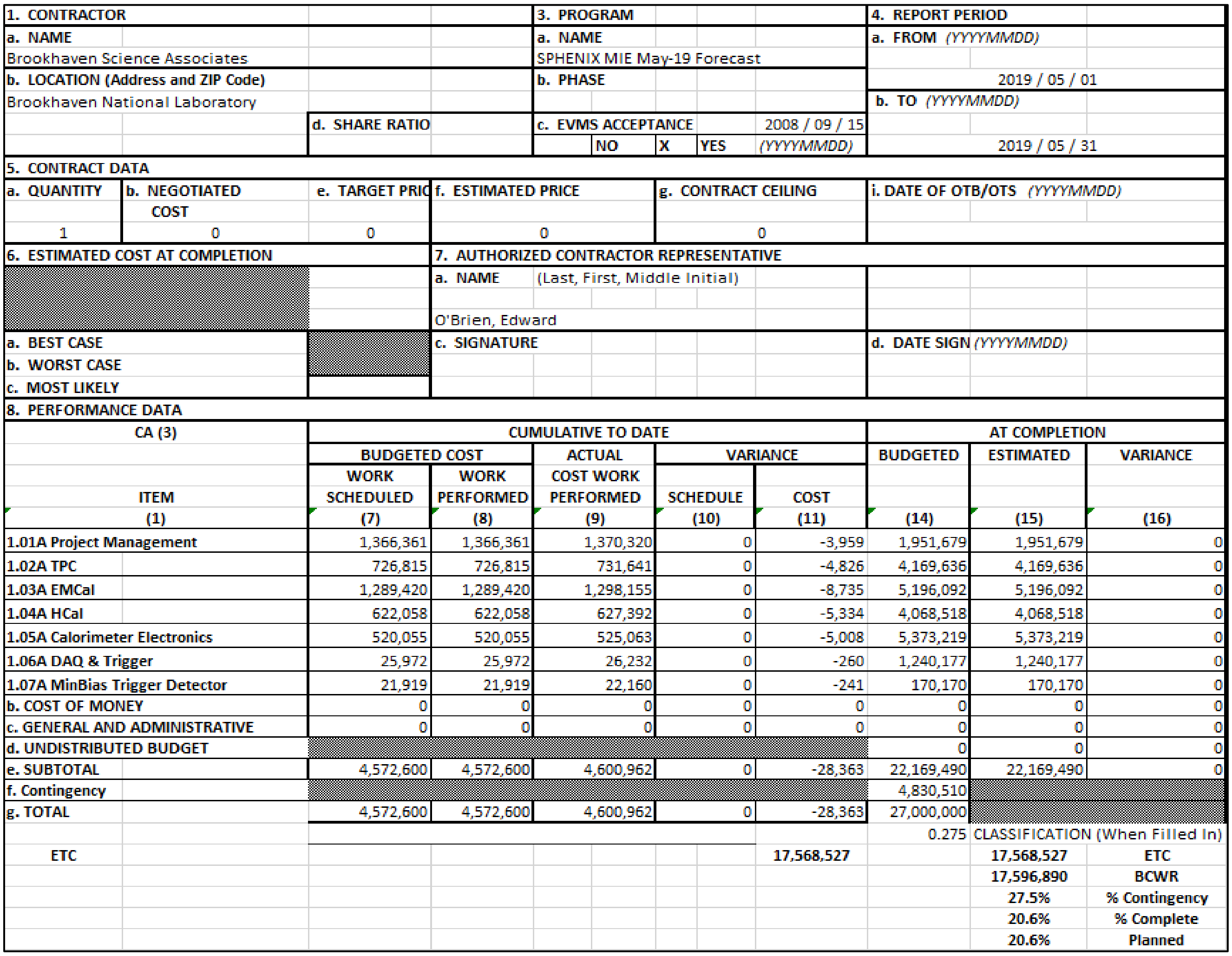
The cost for the TPC electronics was confirmed, while that for the calorimeter electronics, specifically the pre-production digitizers noted above, was updated. Since the design has matured for both the TPC and calorimeter electronics, as evidenced by delivered prototypes which have now been tested and shown to work and meet specifications, the estimate uncertainty for future work was left as it was at the time of the review. The choice was made not to reduce it at this point due to continued uncertainties in the world market for price and delivery schedule of specialized complex electronics parts. (See Figure 7 – Results of changes to Estimate Uncertainty)

The uncertainty for the tungsten powder for the EMCal was handled separately by an update to the risk registry, as recommended elsewhere in the PD-2/3 report, and an addition to the cost risk was included.

Statusing the Project Schedule to June 1, 2019. Implementing Baseline Changes to Maintain the Early Completion Date.

At the time of the PD-2/3 review a status update of the project schedule had not been performed in several months. In the time between the pre-review statusing and the PD-2/3 review several critical path or near critical path items have been delayed potentially reducing the Project’s 14 months of schedule float. The project statused its schedule, assessed schedule logic and built in margin that could impact the baseline schedule.

The Project schedule has been reviewed and the milestones dates and critical path have not changed. The critical path has made a few minor changes between elements of the work, but it remains confined to the calorimeter electronics work (WBS 1.5.2) in its earlier parts and the EMCal production work (WBS 1.3.2) in its later parts, as before. We deliberately kept some schedule margin between EMCAL (WBS 1.3.2) and Calorimeter FEE (WBS 1.5.2) to allow for some activities being pushed into the future when we statused the schedule and moved the data date. We paid particular attention to various links between activities and sections of the WBS, which improved our understanding of the activities driving the schedule and the critical path. A few unnecessary constraints were removed from the activities describing the installation of the EMCal FEE (WBS 1.5.2) into the EMCal Sectors (WBS 1.3.2.2). The schedule margin built into the EMCal Electronics allowed us to preserve the Project Early Finish in October 2021 and the 14 months. See Figure 5 Critical Path and Figure 6 PMP Milestone Schedule.



1. CONTRACTOR		**3. PROGRAM**	**4. REPORT PERIOD**
a. NAME		**a. NAME**	**a. FROM** *(YYYYMMDD)*
Brookhaven Science Associates		SPHENIX MIE May-19 Forecast	2019 / 05 / 01
b. LOCATION (Address and ZIP Code)		**b. PHASE**	**b. TO** *(YYYYMMDD)*
Brookhaven National Laboratory	**d. SHARE RATIO**	**c. EVMS ACCEPTANCE** 2008 / 09 / 15 NO X YES *(YYYYMMDD)*	2019 / 05 / 31

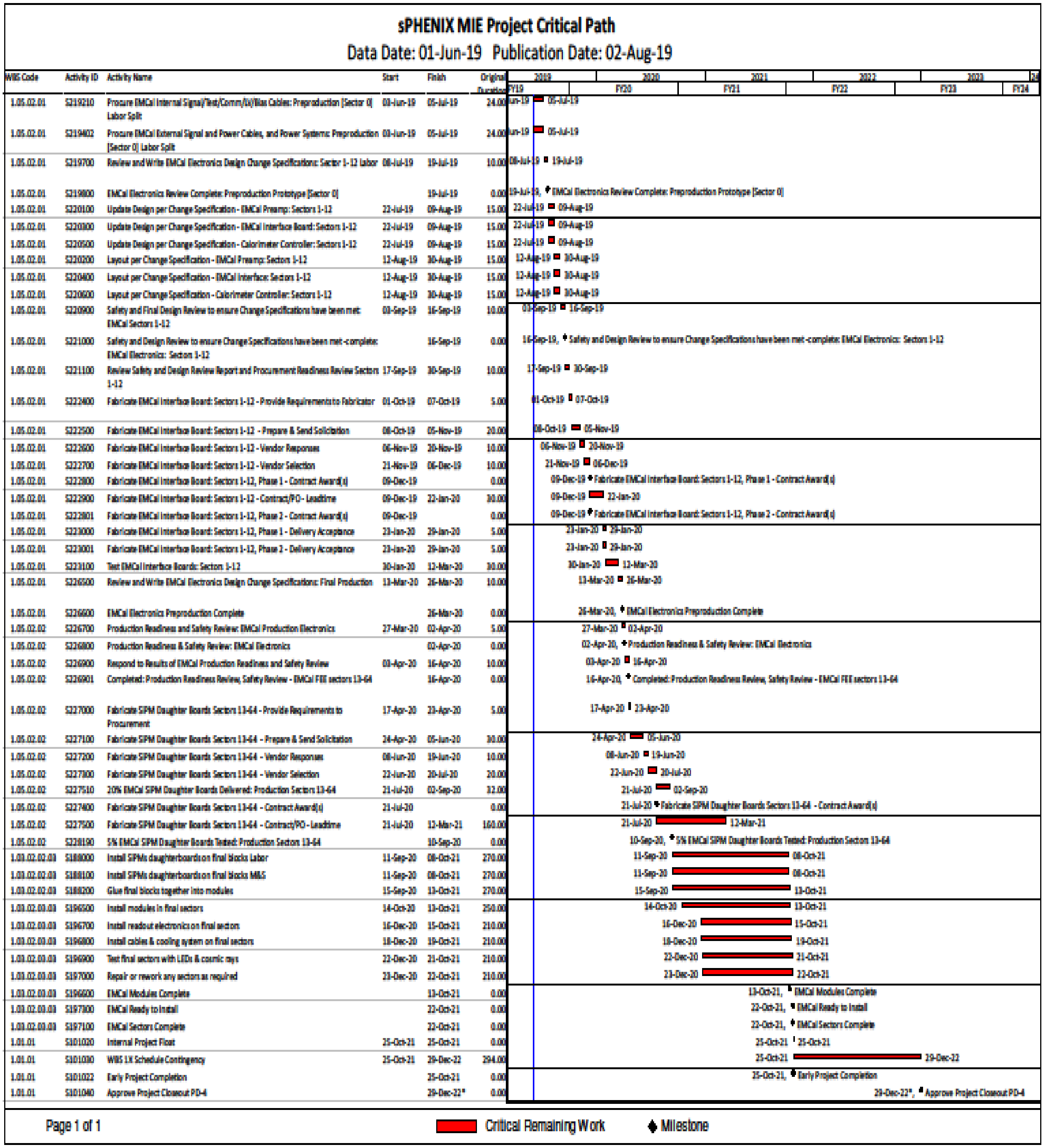
5. CONTRACT DATA					
a. QUANTITY	**b. NEGOTIATED COST**	**e. TARGET PRIC**	**f. ESTIMATED PRICE**	**g. CONTRACT CEILING**	**i. DATE OF OTB/OTS** *(YYYYMMDD)*
1	0	0	0	0	

6. ESTIMATED COST AT COMPLETION		**7. AUTHORIZED CONTRACTOR REPRESENTATIVE**	
		a. NAME (Last, First, Middle Initial) O'Brien, Edward	
a. BEST CASE		**c. SIGNATURE**	**d. DATE SIGN** *(YYYYMMDD)*
b. WORST CASE			
c. MOST LIKELY			

8. PERFORMANCE DATA

CA (3)	CUMULATIVE TO DATE					AT COMPLETION		
	BUDGETED COST		ACTUAL	VARIANCE		BUDGETED	ESTIMATED	VARIANCE
ITEM (1)	WORK SCHEDULED (7)	WORK PERFORMED (8)	COST WORK PERFORMED (9)	SCHEDULE (10)	COST (11)	(14)	(15)	(16)
1.01A Project Management	1,366,361	1,366,361	1,370,320	0	-3,959	1,951,679	1,951,679	0
1.02A TPC	726,815	726,815	731,641	0	-4,826	4,169,636	4,169,636	0
1.03A EMCal	1,289,420	1,289,420	1,298,155	0	-8,735	5,196,092	5,196,092	0
1.04A HCal	622,058	622,058	627,392	0	-5,334	4,068,518	4,068,518	0
1.05A Calorimeter Electronics	520,055	520,055	525,063	0	-5,008	5,373,219	5,373,219	0
1.06A DAQ & Trigger	25,972	25,972	26,232	0	-260	1,240,177	1,240,177	0
1.07A MinBias Trigger Detector	21,919	21,919	22,160	0	-241	170,170	170,170	0
b. COST OF MONEY	0	0	0	0	0	0	0	0
c. GENERAL AND ADMINISTRATIVE	0	0	0	0	0	0	0	0
d. UNDISTRIBUTED BUDGET						0	0	0
e. SUBTOTAL	4,572,600	4,572,600	4,600,962	0	-28,363	22,169,490	22,169,490	0
f. Contingency						4,830,510		
g. TOTAL	4,572,600	4,572,600	4,600,962	0	-28,363	27,000,000		
						0.275	CLASSIFICATION (When Filled In)	
ETC					17,568,527		17,568,527	ETC
							17,596,890	BCWR
							27.5%	% Contingency
							20.6%	% Complete
							20.6%	Planned

Figure 4: Cost Performance Report generated after sPHENIX Project Baseline was set as of May 31, 2019.



sPHENIX MIE Project Critical Path

Data Date: 01-Jun-19 Publication Date: 02-Aug-19

WBS Code	Activity ID	Activity Name	Start	Finish	Original Duration
1.05.02.01	S219210	Procure EMCal Internal Signal/Test/Comm/LV/Bias Cables: Preproduction [Sector 0] Labor Split	03-Jun-19	05-Jul-19	24.00
1.05.02.01	S219402	Procure EMCal External Signal and Power Cables, and Power Systems: Preproduction [Sector 0] Labor Split	03-Jun-19	05-Jul-19	24.00
1.05.02.01	S219700	Review and Write EMCal Electronics Design Change Specifications: Sector 1-12 Labor	08-Jul-19	19-Jul-19	10.00
1.05.02.01	S219800	EMCal Electronics Review Complete: Preproduction Prototype [Sector 0]		19-Jul-19	0.00
1.05.02.01	S220100	Update Design per Change Specification - EMCal Preamp: Sectors 1-12	22-Jul-19	09-Aug-19	15.00
1.05.02.01	S220300	Update Design per Change Specification - EMCal Interface Board: Sectors 1-12	22-Jul-19	09-Aug-19	15.00
1.05.02.01	S220500	Update Design per Change Specification - Calorimeter Controller: Sectors 1-12	22-Jul-19	09-Aug-19	15.00
1.05.02.01	S220200	Layout per Change Specification - EMCal Preamp: Sectors 1-12	12-Aug-19	30-Aug-19	15.00
1.05.02.01	S220400	Layout per Change Specification - EMCal Interface: Sectors 1-12	12-Aug-19	30-Aug-19	15.00
1.05.02.01	S220600	Layout per Change Specification - Calorimeter Controller: Sectors 1-12	12-Aug-19	30-Aug-19	15.00
1.05.02.01	S220900	Safety and Final Design Review to ensure Change Specifications have been met: EMCal Sectors 1-12	03-Sep-19	16-Sep-19	10.00
1.05.02.01	S221000	Safety and Design Review to ensure Change Specifications have been met -complete: EMCal Electronics: Sectors 1-12		16-Sep-19	0.00
1.05.02.01	S221100	Review Safety and Design Review Report and Procurement Readiness Review Sectors 1-12	17-Sep-19	30-Sep-19	10.00
1.05.02.01	S222400	Fabricate EMCal Interface Board: Sectors 1-12 - Provide Requirements to Fabricator	01-Oct-19	07-Oct-19	5.00
1.05.02.01	S222500	Fabricate EMCal Interface Board: Sectors 1-12 - Prepare & Send Solicitation	08-Oct-19	05-Nov-19	20.00
1.05.02.01	S222600	Fabricate EMCal Interface Board: Sectors 1-12 - Vendor Responses	06-Nov-19	20-Nov-19	10.00
1.05.02.01	S222700	Fabricate EMCal Interface Board: Sectors 1-12 - Vendor Selection	21-Nov-19	06-Dec-19	10.00
1.05.02.01	S222800	Fabricate EMCal Interface Board: Sectors 1-12, Phase 1 - Contract Award(s)	09-Dec-19		0.00
1.05.02.01	S222900	Fabricate EMCal Interface Board: Sectors 1-12 - Contract/PO - Leadtime	09-Dec-19	22-Jan-20	30.00
1.05.02.01	S222801	Fabricate EMCal Interface Board: Sectors 1-12, Phase 2 - Contract Award(s)	09-Dec-19		0.00
1.05.02.01	S223000	Fabricate EMCal Interface Board: Sectors 1-12, Phase 1 - Delivery Acceptance	23-Jan-20	29-Jan-20	5.00
1.05.02.01	S223001	Fabricate EMCal Interface Board: Sectors 1-12, Phase 2 - Delivery Acceptance	23-Jan-20	29-Jan-20	5.00
1.05.02.01	S223100	Test EMCal Interface Boards: Sectors 1-12	30-Jan-20	12-Mar-20	30.00
1.05.02.01	S226500	Review and Write EMCal Electronics Design Change Specifications: Final Production	13-Mar-20	26-Mar-20	10.00
1.05.02.01	S226600	EMCal Electronics Preproduction Complete		26-Mar-20	0.00
1.05.02.02	S226700	Production Readiness and Safety Review: EMCal Production Electronics	27-Mar-20	02-Apr-20	5.00
1.05.02.02	S226800	Production Readiness & Safety Review: EMCal Electronics		02-Apr-20	0.00
1.05.02.02	S226900	Respond to Results of EMCal Production Readiness and Safety Review	03-Apr-20	16-Apr-20	10.00
1.05.02.02	S226901	Completed: Production Readiness Review, Safety Review - EMCal FEE sectors 13-64		16-Apr-20	0.00
1.05.02.02	S227000	Fabricate SiPM Daughter Boards Sectors 13-64 - Provide Requirements to Procurement	17-Apr-20	23-Apr-20	5.00
1.05.02.02	S227100	Fabricate SiPM Daughter Boards Sectors 13-64 - Prepare & Send Solicitation	24-Apr-20	05-Jun-20	30.00
1.05.02.02	S227200	Fabricate SiPM Daughter Boards Sectors 13-64 - Vendor Responses	08-Jun-20	19-Jun-20	10.00
1.05.02.02	S227300	Fabricate SiPM Daughter Boards Sectors 13-64 - Vendor Selection	22-Jun-20	20-Jul-20	20.00
1.05.02.02	S227510	20% EMCal SiPM Daughter Boards Delivered: Production Sectors 13-64	21-Jul-20	02-Sep-20	32.00
1.05.02.02	S227400	Fabricate SiPM Daughter Boards Sectors 13-64 - Contract Award(s)	21-Jul-20		0.00
1.05.02.02	S227500	Fabricate SiPM Daughter Boards Sectors 13-64 - Contract/PO - Leadtime	21-Jul-20	12-Mar-21	160.00
1.05.02.02	S228190	5% EMCal SiPM Daughter Boards Tested: Production Sectors 13-64		10-Sep-20	0.00
1.03.02.02.03	S188000	Install SiPMs daughterboards on final blocks Labor	11-Sep-20	08-Oct-21	270.00
1.03.02.02.03	S188100	Install SiPMs daughterboards on final blocks M&S	11-Sep-20	08-Oct-21	270.00
1.03.02.02.03	S188200	Glue final blocks together into modules	15-Sep-20	13-Oct-21	270.00
1.03.02.03.03	S196500	Install modules in final sectors	14-Oct-20	13-Oct-21	250.00
1.03.02.03.03	S196700	Install readout electronics on final sectors	16-Dec-20	15-Oct-21	210.00
1.03.02.03.03	S196800	Install cables & cooling system on final sectors	18-Dec-20	19-Oct-21	210.00
1.03.02.03.03	S196900	Test final sectors with LEDs & cosmic rays	22-Dec-20	21-Oct-21	210.00
1.03.02.03.03	S197000	Repair or rework any sectors as required	23-Dec-20	22-Oct-21	210.00
1.03.02.03.03	S196600	EMCal Modules Complete		13-Oct-21	0.00
1.03.02.03.03	S197300	EMCal Ready to Install		22-Oct-21	0.00
1.03.02.03.03	S197100	EMCal Sectors Complete		22-Oct-21	0.00
1.01.01	S101020	Internal Project Float	25-Oct-21	25-Oct-21	0.00
1.01.01	S101030	WBS 1X Schedule Contingency	25-Oct-21	29-Dec-22	294.00
1.01.01	S101022	Early Project Completion		25-Oct-21	0.00
1.01.01	S101040	Approve Project Closeout PD-4		29-Dec-22*	0.00

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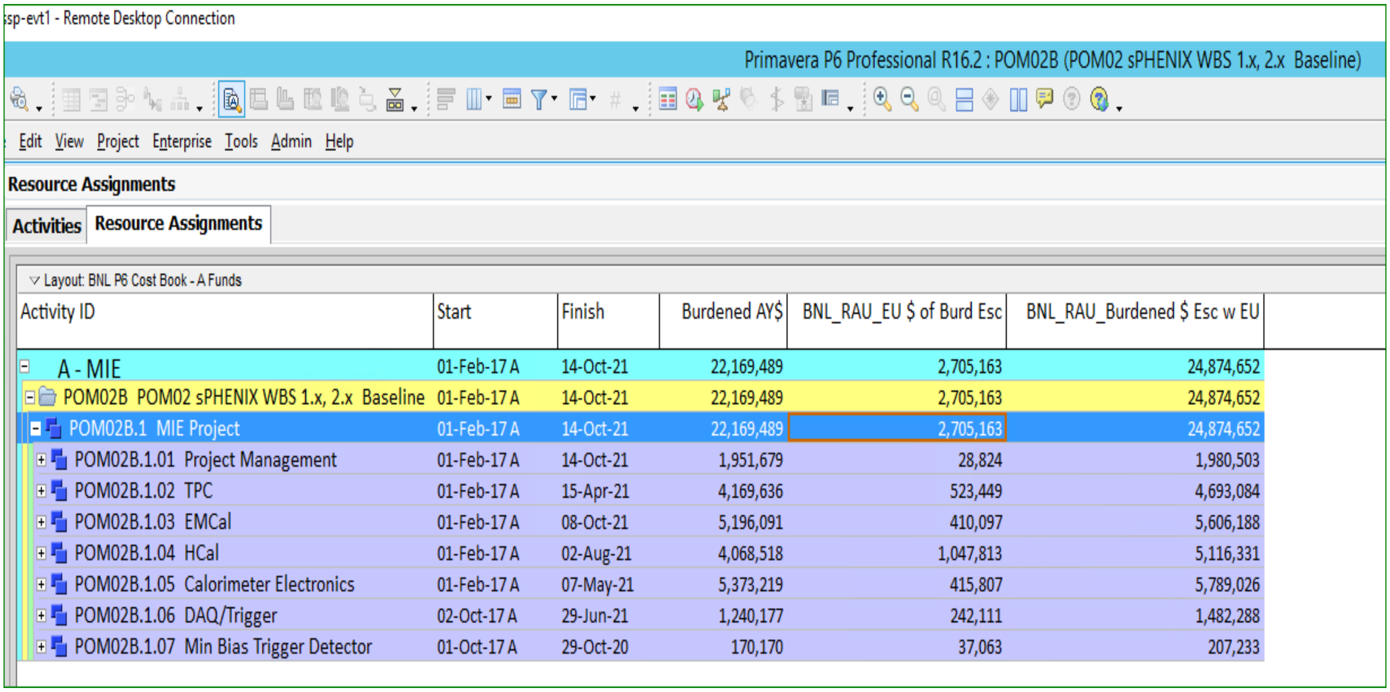
🟥 Critical Remaining Work ◆ Milestone

Figure 5: Critical Path for sPHENIX MIE

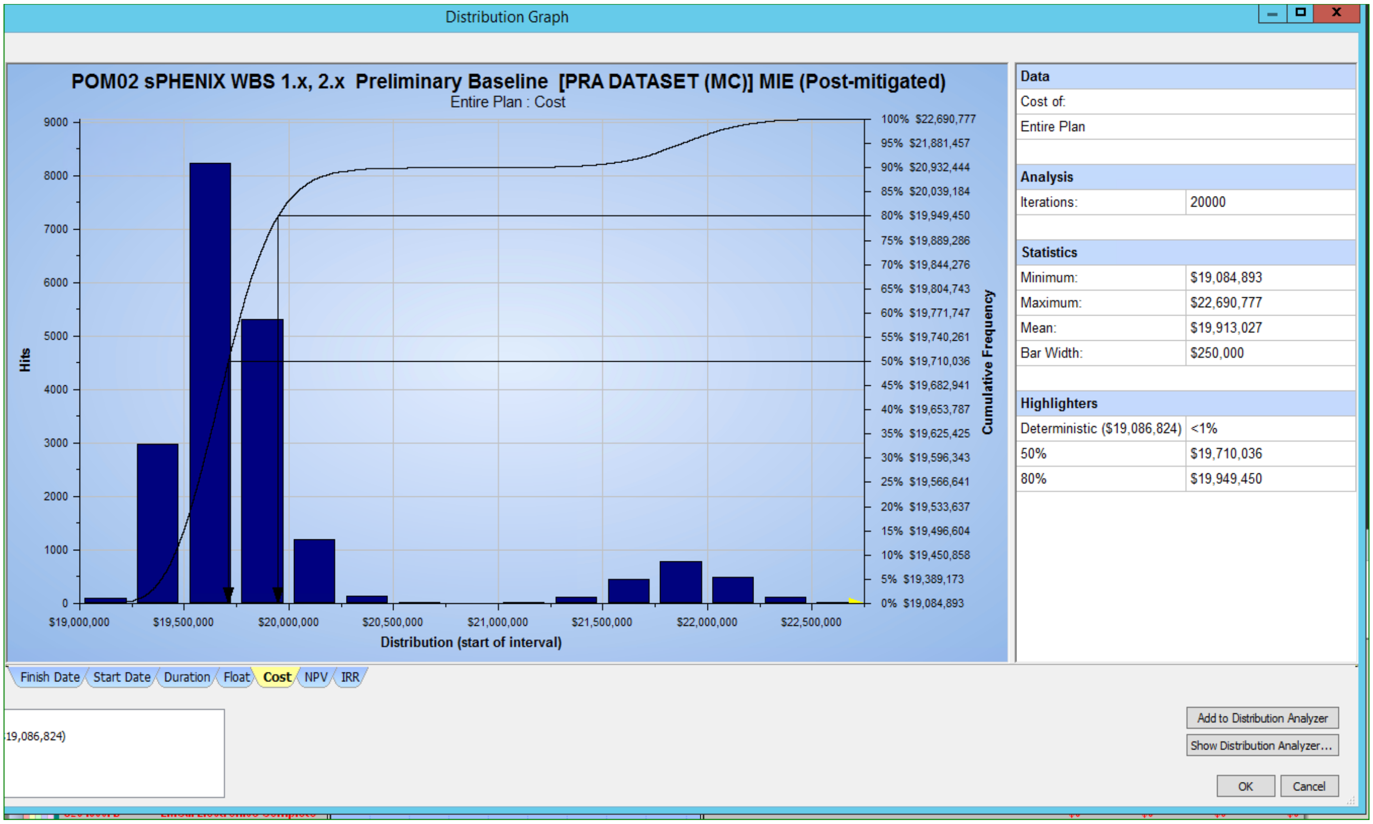
WBS	Level 1 & 2 Project Milestones	Date
1.01.01	**Approve Project Baseline and Construction PD2/3**	19-Sep
1.02.02.02	TPC Module Factories Preproduction Readiness Review	19-Dec
1.03.02.03.02	EMCal Preproduction Sector 0 Assembled	19-Dec
1.02.06.02	TPC DAM Production Readiness Review	20-Feb
1.05.02.03	HCal Preproduction FEE Complete	20-Apr
1.05.02.01	EMCal Electronics Preproduction Complete	20-May
1.03.01.03.01	EMCal W Powder Acquisition Complete	20-Jun
1.03.02.03.03	EMCal Prod. Readiness Review Blocks/Modules/Sectors Complete	20-Jul
1.02.05.03	SAMPA ASIC Performance Accepted	20-Sep
1.05.01	EMCal/HCal SiPM Sensor Procurement Complete	20-Oct
1.05.02.04	HCal SiPM Boards Assembly Complete	20-Nov
1.02.06.03	TPC DAM Felix 2.0 Production Complete	21-Jan
1.06.02.03	Trigger LL1 Preproduction complete	21-Feb
1.05.02.02	EMCal SiPM Boards Production Complete	21-Mar
1.04.04.02	First Outer HCAL Sector Ready to Install	21-Apr
1.04.01	Inner HCAL Ready for Installation	21-Apr
1.02.01.06	GEM Production Complete	21-May
1.06.01.03	DAQ Production: DAQ Ready for Operation	21-May
1.03.01.03.01	EMCal Scintillating Fiber Acquisition Complete	21-May
1.05.02.04	HCal Electronics Complete: Production	21-Jun
1.02.05.04	TPC FEE Production Complete	21-Jul
1.05.02.02	EMCAL Electronics Complete	21-Jul
1.05.03.02	Calorimeter Electronics Complete	21-Jul
1.07	Min Bias Detector Ready to Install	21-Sep
1.06.03.03	GL1 Ready to Operate	21-Sep
1.04.04.02	Last Outer HCAL Sector Ready to Install	21-Oct
1.02.01.08	TPC Ready to Install (Assembly Complete)	21-Oct
1.06.02.04	LL1 Trigger Production Complete	21-Oct
1.06.02.04	LL1 Ready to Operate	21-Oct
1.02.06.03	TPC DAM Production Complete	21-Oct
1.03.02.03.03	EMCal Ready to Install	21-Oct
1.01.01	Early Project Completion	21-Oct
1.01.01	**Approve Project Closeout PD-4**	22-Dec

Figure 6: Level 2 Subsystem technical milestones of the sPHENIX project.



Activity ID	Start	Finish	Burdened AY$	BNL_RAU_EU $ of Burd Esc	BNL_RAU_Burdened $ Esc w EU
A - MIE	01-Feb-17 A	14-Oct-21	22,169,489	2,705,163	24,874,652
POM02B POM02 sPHENIX WBS 1.x, 2.x Baseline	01-Feb-17 A	14-Oct-21	22,169,489	2,705,163	24,874,652
POM02B.1 MIE Project	01-Feb-17 A	14-Oct-21	22,169,489	2,705,163	24,874,652
POM02B.1.01 Project Management	01-Feb-17 A	14-Oct-21	1,951,679	28,824	1,980,503
POM02B.1.02 TPC	01-Feb-17 A	15-Apr-21	4,169,636	523,449	4,693,084
POM02B.1.03 EMCal	01-Feb-17 A	08-Oct-21	5,196,091	410,097	5,606,188
POM02B.1.04 HCal	01-Feb-17 A	02-Aug-21	4,068,518	1,047,813	5,116,331
POM02B.1.05 Calorimeter Electronics	01-Feb-17 A	07-May-21	5,373,219	415,807	5,789,026
POM02B.1.06 DAQ/Trigger	02-Oct-17 A	29-Jun-21	1,240,177	242,111	1,482,288
POM02B.1.07 Min Bias Trigger Detector	01-Oct-17 A	29-Oct-20	170,170	37,063	207,233

Figure 7: Results of changes in Estimate Uncertainty



Data	
Cost of:	
Entire Plan	
Analysis	
Iterations:	20000
Statistics	
Minimum:	$19,084,893
Maximum:	$22,690,777
Mean:	$19,913,027
Bar Width:	$250,000
Highlighters	
Deterministic ($19,086,824)	<1%
50%	$19,710,036
80%	$19,949,450

19,086,824)

Figure 8: Risk results from running the Monte Carlo on data in the revised risk registry.

Response to Recommendation 4:

"Before PD-2/3, the TPC group needs to use their first set of preproduction chambers to simultaneously study the actual Ion Back Flow (IBF), energy resolution and discharge stability for their proposed gas mixture as a function of possible operating point settings for the full range of GEM voltages and transfer fields. This is to be done with the front mesh in place (if that continues as an option) to confirm that an operating point exists that meets all sPHENIX requirements with their proposed gas mixture."

TPC Operation Point

Executive Summary

- Production Chambers installed into IROC measurement apparatus via backplane modification.
- IBF studied, matches spec. of the TDR. Energy resolution not studied because it is not required for sPHENIX.
- Stability tested under X-ray exposure (same criterion as ALICE Inner Read Out Chamber (IROC) certification tests).
- Mesh option discontinued in consultation with ALICE experts at Yale & CERN.

Background Information

The sPHENIX TPC operation is modeled closely after the design for ALICE in the use of a quad GEM-stack to allow continuous non-gated operation of the TPC to allow for high rate. As a result, we benefit significantly from the extensive R&D performed by ALICE in establishing the operation of the gain stage for their experiment. Nonetheless, our design must differ from theirs somewhat due to the different performance parameter required by the experimental program. Specifically and most significantly, the gas choice of ALICE ($Ne:CO_2:N_2$, 85.7:9.5:4.8) and sPHENIX ($Ne:CF_4$, 50:50) must differ due to the different goals for the two devices. While both devices are required to deliver high efficiency and high purity pattern tracking, the ALICE design favors particle ID using dE/dx, whereas the sPHENIX design favors high momentum resolution. How this difference drives the gas choice is shown in Figure 9.

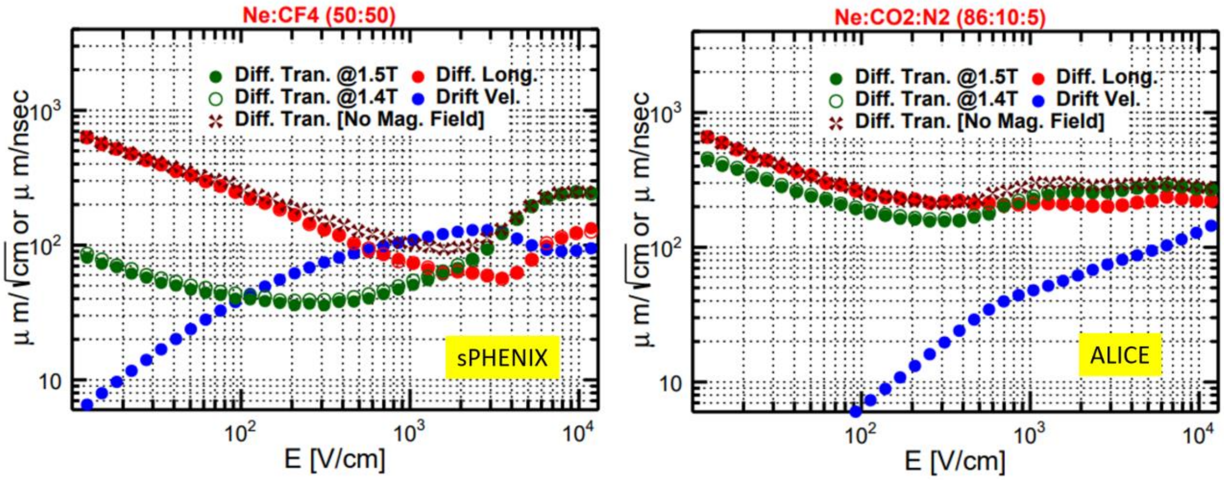


Figure 9: Comparison of diffusion and drift velocity for sPHENIX and ALICE gasses. Most important is the small diffusion (Green Dots) necessary for momentum resolution in sPHENIX.

At the 400 V/cm drift field point, sPHENIX gas has a transverse diffusion constant of $D{\sim}40\,\frac{\mu m}{\sqrt{cm}}$ whereas ALICE has more than triple this value. Were sPHENIX to choose the ALICE gas, our momentum resolution specification for Upsilon physics would be impossible to achieve. For this reason, we must pursue only “cold” (low diffusion gasses). The leading additive for cold gas is CF_4. It is because we have a different gas that we cannot simply use the ALICE operating point of their GEM-stack as an “existence proof” of a viable operating point for our case.

CF_4 Concentration Considerations

Although CF_4 is uniquely favorable in its diffusion performance, there are several possible drawbacks that must be considered. First, CF_4 can be a corrosive if enough water is present in the gas. During the avalanche process, broken molecules of CF_4 will release free radicals, that in combination with water generate the corrosive effect. This is a well-known phenomenon and has not prevented gas chambers for operating for long periods of time in the past as long as the gas system was suitably clean (as will be the case in sPHENIX). Our experience with the PHENIX Hadron Blind Detector (HBD), operating in pure CF_4 under much tighter constraints, is more than enough regarding gas purity.

The second consideration is electron attachment during operation. CF_4 has a large attachment cross section for electrons that, in any given gas mixture, is a function of electric field as shown in Figure 10 for two different gasses: Ne:CF_4 90:10 and Ne:CF_4 50:50.

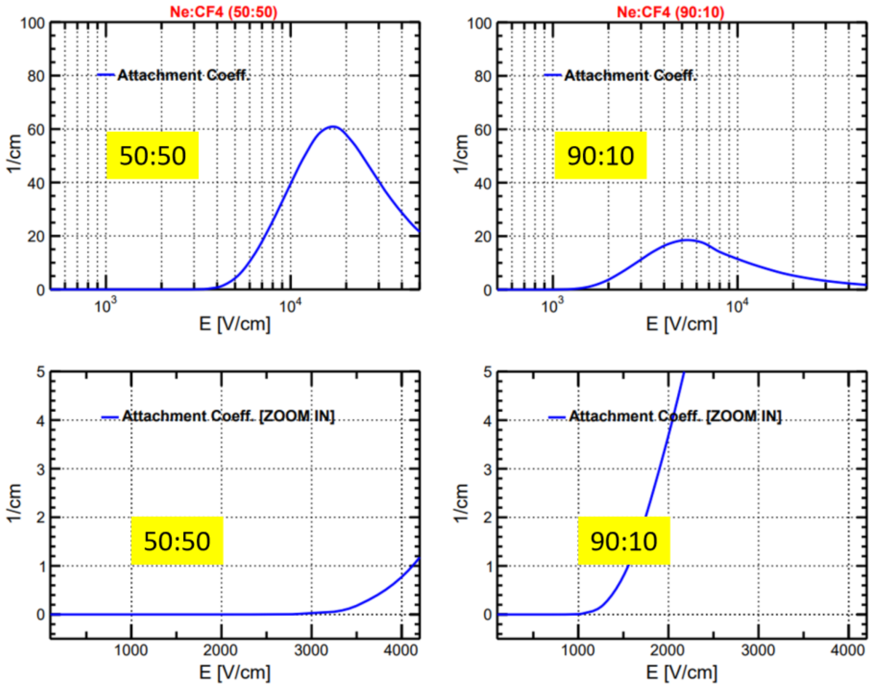


Figure 10: Attachment Coefficient as a function of electric field for two different gas mixtures of Ne:CF4.

Although the peak absorption grows with CF_4 concentration, the onset as a function of electric field varies. As discussed below, the ALICE solution for low Ion Back Flow utilizes (albeit in a different gas) large electric fields in the transfer gap (at the time of this writing 3500 V/cm). As such, the 90:10 mixture would not be a viable choice as more than 99% of electrons would be lost in the transfer gap. Although the 90:10 mixture was used in normal (high IBF) mode during tests in the past, current data has focused on the 50:50 mixture. It is useful to note that ALICE made studies of 80:20 mixtures in the early days and suggested in private communication that this mixture could possibly be viable. They abandoned CF_4 for chemical reasons. In their case, operation was achieved in the presence of high attachment, but compensated with high gain (an unusual operating mode). We have chosen instead to increase the CF_4 to the point that we avoid the absorption edge entirely (standard operating mode).

Characteristics of a Low IBF GEM-stack

ALICE performed extensive studies of the performance of GEM-stacks and Ion Back Flow. These studies guide the current world understanding of what aspects of the avalanche process are critical in creating low IBF and demonstrate that only laboratory measurements can be used to be certain of the eventual performance. There are two dominant mechanisms of suppressing ions. The first is field ratio. Any electrode (whether GEM, microMEGAS, or simple mesh) that generates a difference in entrance and exit field does so by being either the source or termination point for electric field lines. As a result, a significant fraction of particles traveling toward the electrode from the high field side will end on the electrode. Thus, electrons traveling in one direction experiencing low→high field transmissions can be navigated through, while ions traveling in the opposite direction will frequently terminate on the electrode. The GEM configuration of both ALICE and sPHENIX is shown in Figure 11.

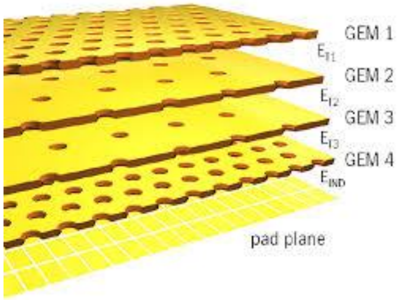


Figure 11: GEM configuration of ALICE and sPHENIX.

The fields currently chosen by ALICE are E_{T1}=3500 V/cm, E_{T2}=3500 V/cm, E_{T3}=100 V/cm, E_{ind}=3500 V/cm. Because the largest number of ions are present at the last amplification step, the E_{T3}/E_{ind} field step is the significant source of IBF suppression via the "field step" mechanism.

Additionally, and equally significantly, is the effect of using "Large Pitch" (LP) GEMs in the central two layers. When the electric field is large enough in the transfer gap, many field lines will terminate on the GEM surface rather than enter the holes. The larger the field in the gaps, the more field lines terminate on the surface rather than enter the holes. At first glance, this effect would seem to reduce electrons and ions identically, and indeed it does. The difference is that electrons can be "regenerated" by the avalanche in the holes and ions are lost forever.

There is one final takeaway point from the ALICE studies that is key in determining the sPHENIX operation point. Although ALICE studies a wide four-dimensional space of possible transfer/induction field settings, in the end that found that setting $E_{T1}=E_{T2}=E_{ind}$ was negligibly different from final performance of asymmetric settings. Accepting this principle greatly reduces the complexity of optimizing the sPHENIX operating point. Rather than scan the complete space of transfer fields, we can limit our studies to a scan varying $E_{T1}=E_{T2}=E_{ind}$ and search for an operation point for our system.

Note: Conversations with the Yale group have convinced us the mesh is unnecessary and thus not planned to be used in the sPHENIX TPC.

Measurement Apparatus at Yale

Our close relationship with colleagues at Yale has tremendously benefitted the sPHENIX TPC project and particularly so in recent months. Yale was the site that assembled and tested all IROCs (Inner Read Out Chambers) for the ALICE upgrade. Because the IROC project is completed with the delivery of all working chambers to CERN, we were able to utilize the personnel and apparatus used for ALICE chamber testing/certification directly on sPHENIX chambers. Figure 12 shows how this was accomplished.

Figure 12: Modified Inner Read Out Test Chamber.

The horizontal plate shows the modified back plane of an IROC chamber that has had arc-shaped holes cut into the surface so that both an R1 sPHENIX module and an R2 sPHENIX module can be inserted into the ALICE test station. Following that complete IBF and stability under load studies can be performed. This feature allows us to inherit personnel to perform the measurements, apparatus to perform the measurements, as well as stability and uniformity standards from ALICE. IBF and stability tests are necessarily "on the bench". This is because a test beam facility does not provide the intensity to test either one of these. Nonetheless, we also performed test beam measurements on our chamber in low IBF mode. Figure 12 is, in fact, a photo of the delivery of the R2 module from Yale to Stony Brook prior to our test beam campaign.

Bench Test Results

Bench test results were performed as a function of transfer field with $E_{T1}=E_{E2}=E_{ind}$ and E_{T3}=100Volt/cm. At each value of the transfer field, the gain of the module was adjusted using the GEM voltages so as to achieve a value near 2000 (2200 was close to the average). These results are shown in Figure 13.

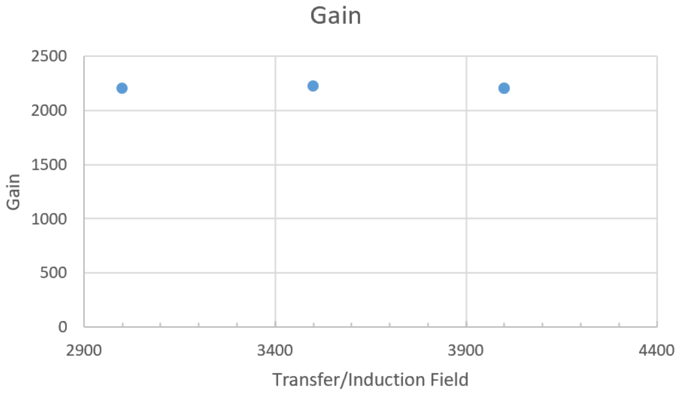


Figure 13: Gain achieved during each of the transfer field settings.

Although the gain was held constant, as expected the IBF results show better and better performance with increasing electric field in the transfer gaps. This is shown in Figure 14.

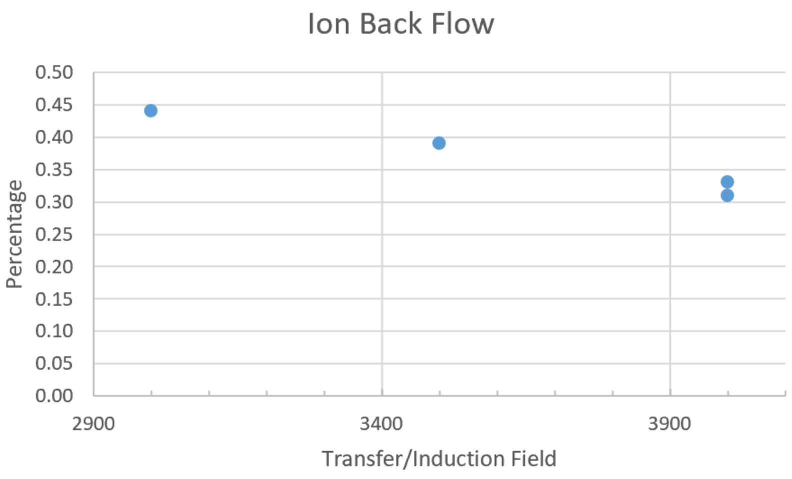


Figure 14: Ion Back Flow (in percent) as a function of transfer field.

The final two settings meet the sPHENIX specification and value used in the CDR (0.3%) and are thereby both acceptable running points for sPHENIX. These final two points differ in the distribution of gain among the individual GEMs rather than the transfer gap fields.

The operating point was also tested for high voltage stability against discharge and passed the same standard as applied to ALICE production chambers under an intense X-ray source load. Based on the X-ray load tests (ALICE criterion) of the GEM modules, beam tests of non-loaded stability and resolution, and Garfield simulations of TPC electron transport we conclude that the sPHENIX TPC using 50:50 Ne:CF4 will meet performance requirements at RHIC luminosities and expected IR radiation loads.

Test Beam Results

The test beam data are still in a preliminary status and known approximations in the analysis, when corrected, will produce better results. Nonetheless, we tested non-loaded stability (no spark of the chamber was ever observed) as well as position resolution. The online result for position resolution is shown in figure 15.

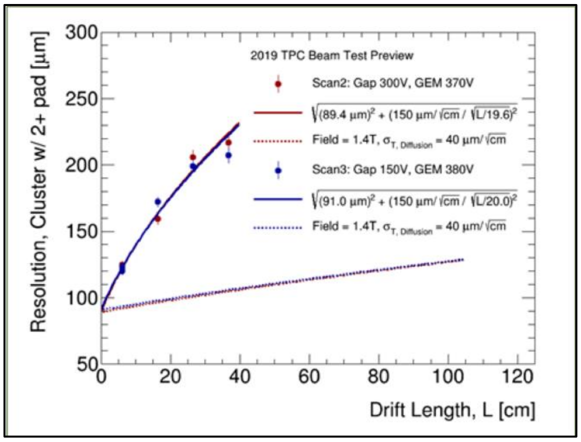


Figure 15: Resolution vs. drift length. Fitted data shows the resolution with no magnetic field, and the dotted lines show calculated performance expected in a 1.4 Tesla field based on the field off data.

The data points are with no magnetic field. The line scales slope by the known improvement of diffusion with 1.4 Tesla field. The result is below 150 μm at all lengths, better than sPHENIX specification.

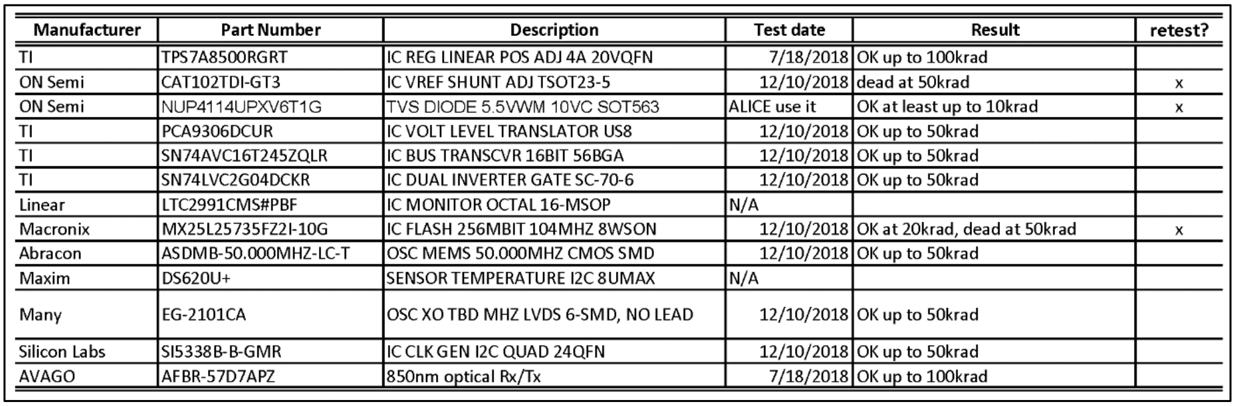
Response to Recommendation 5:

“As indicated in last year’s review, all components on the TPC FEE board needs to be radiation-qualified; this has been largely achieved but some tests remain. Demonstrate the performance of (two) full TPC FEE boards with SAMPA V4 ASICs versus dose up to a TID of at least 100 krad. Once available, repeat this demonstration using full TPC FEE boards with SAMPA V5 ASICs. The Committee then recommends proceeding to PD-2/3.”

We performed an irradiation test for 100 krad using Co-60 gamma source available at the BNL instrumentation. See set-up pictures in the figure 17.

Tests Results for a 50 krad Exposer Performed Before the PD-2/3 review.

The FEE board was irradiated up to 50 krad before the PD-2/3 review. The anticipated radiation level at r=16cm is 5 krad/year or 25 krad for 5 years sPHENIX running. The board will be placed around r=30 cm where 12 krad is expected for 5 years. Therefore, 50 krad already has safety factor of 4. The following table shows all the semi-conductor parts on the board, including an optical transceiver. The result of 50krad irradiation test is also listed. This table was shown at the PD-2/3 review.



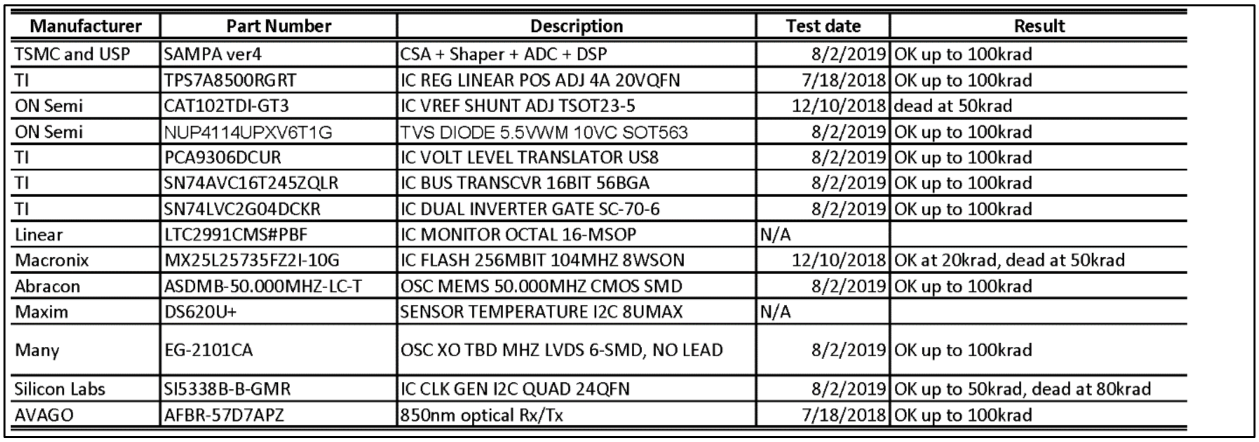
Manufacturer	Part Number	Description	Test date	Result	retest?
TI	TPS7A8500RGRT	IC REG LINEAR POS ADJ 4A 20VQFN	7/18/2018	OK up to 100krad	
ON Semi	CAT102TDI-GT3	IC VREF SHUNT ADJ TSOT23-5	12/10/2018	dead at 50krad	x
ON Semi	NUP4114UPXV6T1G	TVS DIODE 5.5VWM 10VC SOT563	ALICE use it	OK at least up to 10krad	x
TI	PCA9306DCUR	IC VOLT LEVEL TRANSLATOR US8	12/10/2018	OK up to 50krad	
TI	SN74AVC16T245ZQLR	IC BUS TRANSCVR 16BIT 56BGA	12/10/2018	OK up to 50krad	
TI	SN74LVC2G04DCKR	IC DUAL INVERTER GATE SC-70-6	12/10/2018	OK up to 50krad	
Linear	LTC2991CMS#PBF	IC MONITOR OCTAL 16-MSOP	N/A		
Macronix	MX25L25735FZ2I-10G	IC FLASH 256MBIT 104MHZ 8WSON	12/10/2018	OK at 20krad, dead at 50krad	x
Abracon	ASDMB-50.000MHZ-LC-T	OSC MEMS 50.000MHZ CMOS SMD	12/10/2018	OK up to 50krad	
Maxim	DS620U+	SENSOR TEMPERATURE I2C 8UMAX	N/A		
Many	EG-2101CA	OSC XO TBD MHZ LVDS 6-SMD, NO LEAD	12/10/2018	OK up to 50krad	
Silicon Labs	SI5338B-B-GMR	IC CLK GEN I2C QUAD 24QFN	12/10/2018	OK up to 50krad	
AVAGO	AFBR-57D7APZ	850nm optical Rx/Tx	7/18/2018	OK up to 100krad	

Table 1: TPC FEE board component performance after 50 krad radiation exposure.

All the parts except for the EEPROM (Macronix products) and the bandgap reference (On Semi CAT102TDI-GT3) survived 50 krad. We will discuss mitigation plan later in this section. The SAMPA chip was not tested at that time, since we knew that it is good up to 25-30 krad from the test for the SAMPA ver2. The expert of U. Sao Paulo said that the process is 130 nm CMOS and is very tough against radiation.

Test result at 100 krad Radiation Exposure in August 2019

We performed Co-60 irradiation to the FEE board again, and check its health at 80 and 100 krad. At 80 krad, all the parts survived at 50 krad were found also to survive, except for the PLL (Silicon Labs product). The PLL became non-programmable. We provided clocks to SAMPA and FPGA by bypassing the PLL, and then successfully read out pedestal data from SAMPA. The data looked normal. The status was same at 100 krad. The updated table is shown below:



Manufacturer	Part Number	Description	Test date	Result
TSMC and USP	SAMPA ver4	CSA + Shaper + ADC + DSP	8/2/2019	OK up to 100krad
TI	TPS7A8500RGRT	IC REG LINEAR POS ADJ 4A 20VQFN	7/18/2018	OK up to 100krad
ON Semi	CAT102TDI-GT3	IC VREF SHUNT ADJ TSOT23-5	12/10/2018	dead at 50krad
ON Semi	NUP4114UPXV6T1G	TVS DIODE 5.5VWM 10VC SOT563	8/2/2019	OK up to 100krad
TI	PCA9306DCUR	IC VOLT LEVEL TRANSLATOR US8	8/2/2019	OK up to 100krad
TI	SN74AVC16T245ZQLR	IC BUS TRANSCVR 16BIT 56BGA	8/2/2019	OK up to 100krad
TI	SN74LVC2G04DCKR	IC DUAL INVERTER GATE SC-70-6	8/2/2019	OK up to 100krad
Linear	LTC2991CMS#PBF	IC MONITOR OCTAL 16-MSOP	N/A	
Macronix	MX25L25735FZ2I-10G	IC FLASH 256MBIT 104MHZ 8WSON	12/10/2018	OK at 20krad, dead at 50krad
Abracon	ASDMB-50.000MHZ-LC-T	OSC MEMS 50.000MHZ CMOS SMD	8/2/2019	OK up to 100krad
Maxim	DS620U+	SENSOR TEMPERATURE I2C 8UMAX	N/A	
Many	EG-2101CA	OSC XO TBD MHZ LVDS 6-SMD, NO LEAD	8/2/2019	OK up to 100krad
Silicon Labs	SI5338B-B-GMR	IC CLK GEN I2C QUAD 24QFN	8/2/2019	OK up to 50krad, dead at 80krad
AVAGO	AFBR-57D7APZ	850nm optical Rx/Tx	7/18/2018	OK up to 100krad

Table 2: TPC FEE board component performance after 100 krad radiation exposure.

The plots below show the pedestal distributions over 32 channels (one chip) overlaid, before and after 100 krad irradiation. The left plot is before irradiation and the right is after irradiation. They look very similar given the statistics, **proving that the SAMPA and the other survived parts function normally after 100 krads of exposure.**

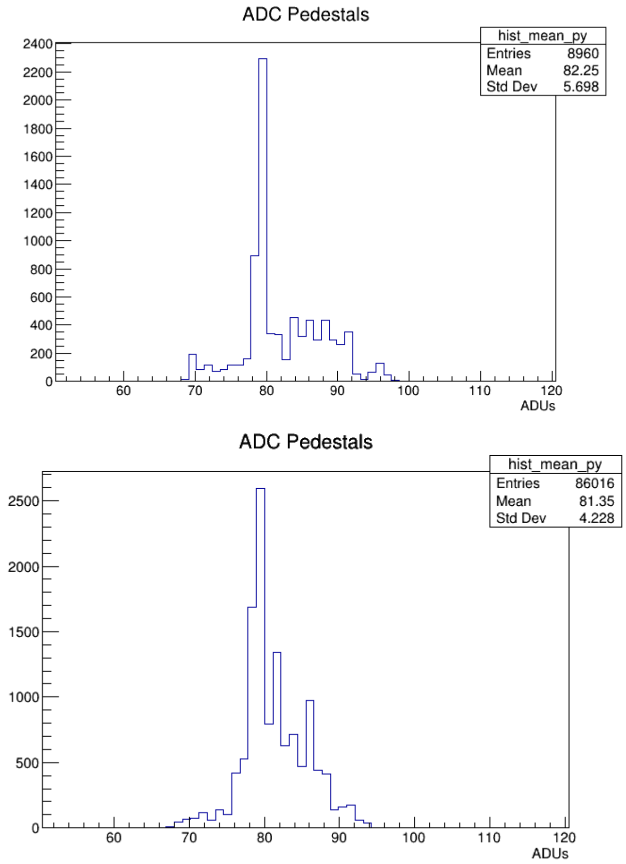


Figure 16: Top plot shows the pedestal distributions over 32 channels (one SAMPA chip) before irradiation. Bottom plot shows the pedestal distribution over 32 channels after 100 krad irradiation.

Mitigation Plan

The anticipated radiation level of the TPC FEE board with the highest exposure in sPHENIX is 12 krad over 5 years. Even at double the exposure, 24 krads, the FEE board should function normally. Note that 12 krad for 5 years is for FEEs located in the most inner section which is 144 out of whole 624 boards. The middle and outer sections will be exposed to a smaller radiation level (~60% for middle and ~40% for outer). If we require the safety factor of 4, EEPROM and the bandgap reference has to be replaced. We have identified the alternate solution for bandgap reference, which is to use the TI TPC7A8500RGRT regulator instead. The EEPROM used for ATLAS experiments which we have thought as the solution was turned out not to survive up to ~40 krad. We explored documents about EEPROM, and found no flash memory would survive above a few tens of krad. This means that we have to use either our choice or ATLAS's EEPROM and replace it in the middle of 5-years running. A mitigation plan for this will be to distribute JTAG interface to the FEEs and configure the FPGA. The JTAG interface can share the optical connection of transmitting beam clock and slow control signals to FEEs.

The PLL was found to be dead between 50 to 80 krad. It is not very likely that we reach that level of integrated radiation. There is an internal PLL in FPGA which can replace its functionality, if the clock difference between transceivers and crystal oscillator is not large, which we can do by choosing an oscillator of suitable frequency. Therefore, this external PLL can be put off from the final board if necessary.

The boards to be affected by EEPROM and PLL issues will be at most 144 out of 624 (most inner).

Figure 17: Irradiation Test set-up

Response to Recommendation 6

“Re-evaluate the contingency associated with large procurements such as the W powder, in view of the recent cost increase in this material and possible pending tariff situation. Once the above is satisfactorily completed, to the satisfaction of the sPHENIX Project Director and reported to the Review Committee, the EMCal can proceed to PD-2/3.”

The Risk Register has been reviewed and the following changes were made:

The probability of the risk “SAMPA Chip 80 nsec development” was increased from 5% to 20%, the probability of the risk “Tungsten Powder cost go up” was increased from 5% to 25% and the probability of all risks for electronics components was increased from 50% to 70%. After these changes were made to the risk registry, the Monte Carlo was run again which resulted in an increase to the Project Risk Contingency of $181K to $1,846K (See Figure 8 – Cost Distribution).

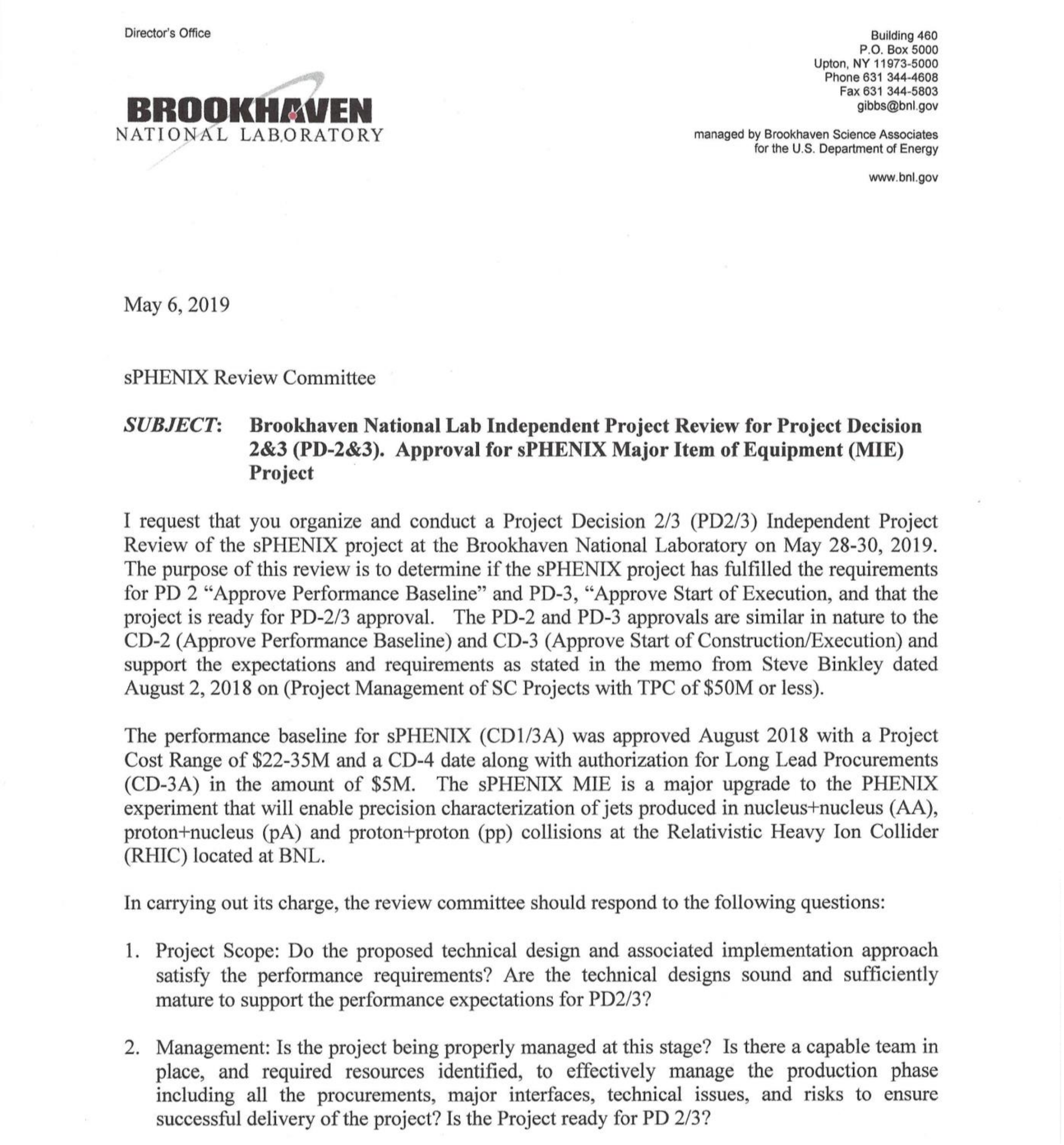
In addition, the estimate uncertainty was re-evaluated for certain important international procurements. The SAMPA WBS (1.02.05.03) development takes place in Brazil. It was reorganized and the cost reduced based on completed work over the spring at the vendor (U. Sao Paulo). The estimate uncertainty was left unchanged for the future work because the design basis and quotes from the chip vendor remain unchanged.

The GEM foils are produced in Switzerland. The GEM cost was confirmed by the CERN laboratory where they will be built, and the laboratory confirmed that they stand ready to perform the requested work for sPHENIX, thus this estimate and its uncertainty were left unchanged.

Numerous electronics components come from international sources. The electronics costs dominated the costs of the TPC and Calorimeter electronics. The TPC electronics was confirmed with vendors since the PD-2/3 review. The costs for the calorimeter electronics, specifically the pre-production digitizers noted above, were updated. Because the design has matured for both the TPC and Calorimeter Electronics, as evidenced by delivered prototypes which have now been tested and shown to work and meet specifications, the estimate uncertainty for future work was left as it was at the time of the PD-2/3 review. The choice was made not to reduce the contingency at this point, even though we are far into the preproduction stage, due to continued uncertainties in the world market for price and delivery schedule of specialized complex electronics parts. (See Figure 7 – Results of Changes to Estimate Uncertainty)

Appendix A:

Review Charge



Director's Office

BROOKHAVEN
NATIONAL LABORATORY

Building 460
P.O. Box 5000
Upton, NY 11973-5000
Phone 631 344-4608
Fax 631 344-5803
gibbs@bnl.gov

managed by Brookhaven Science Associates
for the U.S. Department of Energy

www.bnl.gov

May 6, 2019

sPHENIX Review Committee

***SUBJECT*:** **Brookhaven National Lab Independent Project Review for Project Decision 2&3 (PD-2&3). Approval for sPHENIX Major Item of Equipment (MIE) Project**

I request that you organize and conduct a Project Decision 2/3 (PD2/3) Independent Project Review of the sPHENIX project at the Brookhaven National Laboratory on May 28-30, 2019. The purpose of this review is to determine if the sPHENIX project has fulfilled the requirements for PD 2 "Approve Performance Baseline" and PD-3, "Approve Start of Execution, and that the project is ready for PD-2/3 approval. The PD-2 and PD-3 approvals are similar in nature to the CD-2 (Approve Performance Baseline) and CD-3 (Approve Start of Construction/Execution) and support the expectations and requirements as stated in the memo from Steve Binkley dated August 2, 2018 on (Project Management of SC Projects with TPC of $50M or less).

The performance baseline for sPHENIX (CD1/3A) was approved August 2018 with a Project Cost Range of $22-35M and a CD-4 date along with authorization for Long Lead Procurements (CD-3A) in the amount of $5M. The sPHENIX MIE is a major upgrade to the PHENIX experiment that will enable precision characterization of jets produced in nucleus+nucleus (AA), proton+nucleus (pA) and proton+proton (pp) collisions at the Relativistic Heavy Ion Collider (RHIC) located at BNL.

In carrying out its charge, the review committee should respond to the following questions:

1. Project Scope: Do the proposed technical design and associated implementation approach satisfy the performance requirements? Are the technical designs sound and sufficiently mature to support the performance expectations for PD2/3?
2. Management: Is the project being properly managed at this stage? Is there a capable team in place, and required resources identified, to effectively manage the production phase including all the procurements, major interfaces, technical issues, and risks to ensure successful delivery of the project? Is the Project ready for PD 2/3?

3. Cost and Schedule:_Are the cost and schedule estimates complete, adequate, and reasonable to support the performance baseline?

4. Risk and contingency: Are the project risks properly identified and appropriate mitigation strategies in place? Do the cost and schedule estimates include adequate contingency based on a sound and reasonable risk analysis?

5. Environment, Safety & Health and Quality Assurance (ES&H/QA): Are the ES&H/QA requirements being properly addressed given the project's current stage of development?

6. Prerequisites: Have all the prerequisite activities and documents (see attached definition) necessary to support PD 2/3 approval been completed?

7. Recommendations: Have the recommendations from past reviews been appropriately addressed?

Robert Tribble, Deputy Director for Science and Technology, will serve as the point of contact for this review. I would appreciate receiving your committee's report within 14 days of the review's conclusion.

Sincerely,

Doon Gibbs
Laboratory Director

cc: J. Gillo, DOE
J. Hawkins, DOE
R. Gordon, BHSO/DOE
L. Nelson, BHSO/DOE
B. Mueller, BNL