Management Plan
for the
Silicon Vertex Tracking Detector (VTX)
for PHENIX

at
Brookhaven National Laboratory

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

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1 INTRODUCTION

PHENIX proposes to install a four-layer silicon tracking detector (VTX) in the inner region of PHENIX. The detector will cover range of ~ 2π azimuth and from $-1.2 < \eta < 1.2$ in pseudo-rapidity. For the inner two layers we will use silicon pixel sensors with 50×425 μm pixels bump-bonded to ALICE1LHCb readout chips that have been developed for the ALICE experiment at the CERN LHC. The outer two layers will use silicon strip sensors (known as a strip-pixel sensor) developed by the Instrumentation Division at BNL. With stereoscopic strips of 80 μm $\times$ 3 cm, these devices achieve an effective pixel size of 80×1000 μm. We plan to use the SVX4 readout chip developed at FNAL to readout the strip detectors.

The VTX will substantially enhance the physics capabilities of the PHENIX central arm spectrometers. Our prime motivation is to provide precise measurements of heavy-quark production (charm and beauty) in *A+A*, *p(d)+A*, and polarized *p+p* collisions. These are key measurements for the future RHIC program, both for the heavy ion program as it moves from the discovery phase towards detailed investigation of the properties of the dense nuclear medium created in heavy ion collisions, and for the exploration of the nucleon spin-structure functions. Further details of the physics reach of the proposed VTX system are described in the proposal.

The new detector will be realized in two parallel construction projects, one funded by RIKEN and France and one funded by DOE. US institutions are responsible for the strip detectors, the mechanical system and the infrastructure, while Japanese and French institutions have responsibility for the pixel detectors.

2 FUNCTIONAL REQUIREMENTS

The principal functional requirement of the VTX to meet its physics goals is to provide precise measurements of tracks back to the collision vertex with a transverse distance of closest-approach (DCA) resolution on the order of 100 microns or better after all corrections.

Other general requirements:

- The system must fit into the integration envelope agreed to within PHENIX
- The system must be able to operate inside the PHENIX magnet.
- The system must be safe. The system must meet BNL C-AD safety requirements.
- The system must not significantly reduce the physics capability of other PHENIX detector subsystems.
- The inner two layer of the system must have a radiation length of less than 2.5 %
- The outer two layer of the system must have a radiation length of less than 3.5 %
- The system must operate in a temperature range of 0^o C to 20^o C
- The VTX system must work within the existing PHENIX readout scheme,
    - must store the data on the detector for the LVL1 latency (4 μs),
    - must have a 4-deep buffer of LVL1 accepted events
    - must readout data within 100 μs to its front-end modules (FEMs) off the detector so as to not significantly reduce the maximum rate that of PHENIX Level-1 triggers which is designed to be10 kHz.

These requirements are summarized in the Table 1.

Table 1. PHENIX VTX System Functional Requirements

Pixel size of the pixel layers	50 μm $\times$425 μm
Strip width of the strip layers	80 μm
Radiation length per layer (pixel)	< 2.5 %
Radiation length per layer (strip)	< 3.5 %
Operating temperature	0^o C to 20^o C
LVL1 latency	4 μs
LVL1 Multi-Event buffer depth	4 events
Read-out time	< 100 μs
Read-out rate	> 10 kHz

3 TECHNICAL SCOPE

The PHENIX VTX project is divided into three major subsystem groups: (a) strip detector, (b) pixel detector, and (c) mechanical and infrastructure.

3.1 STRIP DETECTORS

The production and delivery of these detectors are the responsibility of US institutions within PHENIX. The strip detector forms the outer two layers (R3 and R4) of the VTX. It is constructed from individual strip ladders. The number of ladders, channels per ladder are summarized in Table 2. Each strip ladder is comprises of strip-pixel sensors, a read-out-card, and a mechanical stave with cooling. The rest of the strip system includes power, signal and control cables between the ladders and the off-detector front-end-modules (FEMs), and PHENIX-standard data-collection modules (DCMs). Quality assurance procedures and tests will be established at ORNL and BNL to insure that all strip ladders are ready for successful operation in PHENIX.

Table 2: Summary of main parameters of the outer two strip layers

VTX	Layer	R3	R4
Geometrical dimensions	R (cm)	10	14
	Δz (cm)	31.8	38.2
	Area (cm^2)	1960	3400
Channel count	Sensor size R × z (cm^2)	3.43 × 6.36 (384 × 2 strips)	
	Channel size	80 μm × 3 cm (effective 80 × 1000 μm^2)	
	Sensors/ladder	5	6
	Ladders	18	26
	Sensors	90	156
	Readout chips	1080	1872
	Readout channels	138,240	239,616

3.1.1 Definitions

- Strip-pixel sensor is a single-sided two-dimensional strip sensor developed at BNL instrumentation division. One ~3.4 × 6.4 cm strip sensor is divided into two ~3.4 × 3.2 cm sensor areas. Each sensor area has 384 strips in two dimensions (X and U). Thus one sensor has total of 1536 strips.
- The SVX4 is an ASIC developed by FNAL and LBL for the readout of silicon detectors. There are 128 channels on each SVX4 chip. Each strip sensor is wire-bonded to and read-out by twelve SVX4s.
- A Read-Out card (ROC) is a board to read-out one sensor. A ROC has twelve SVX4s that are readout by a custom, digital ASIC: the readout-chip-controller (RCC) placed at the center of the ROC.
- A Sensor module is a sensor glued and wire bonded to a ROC.

- A ladder comprises five (for R3) to six (for R4) sensor modules, bus, mechanical stave, and cooling. A ladder covers the full acceptance in beam direction (z).
- A Pilot Module (PM), mounted near the magnet pole-tip, provides local power regulation, filtering and fusing for each ROC. The PM also routes signals (data, timing and slow controls) between the ladder and the Front-End Module.
- A Front-End Module (FEM) serves as the interface between the ladders and the PHENIX DAQ (Serial Control, Clock & Control, and the Data Collection Module) and will be located outside of the detector acceptance.
- Data Collection Modules (DCM) are the front-end of the PHENIX DAQ system. They collect data from subsystems, format the data, and send the data to the Event Builder. The pixel subsystem will use the 2nd generation DCMs that are now being developed by PHENIX.

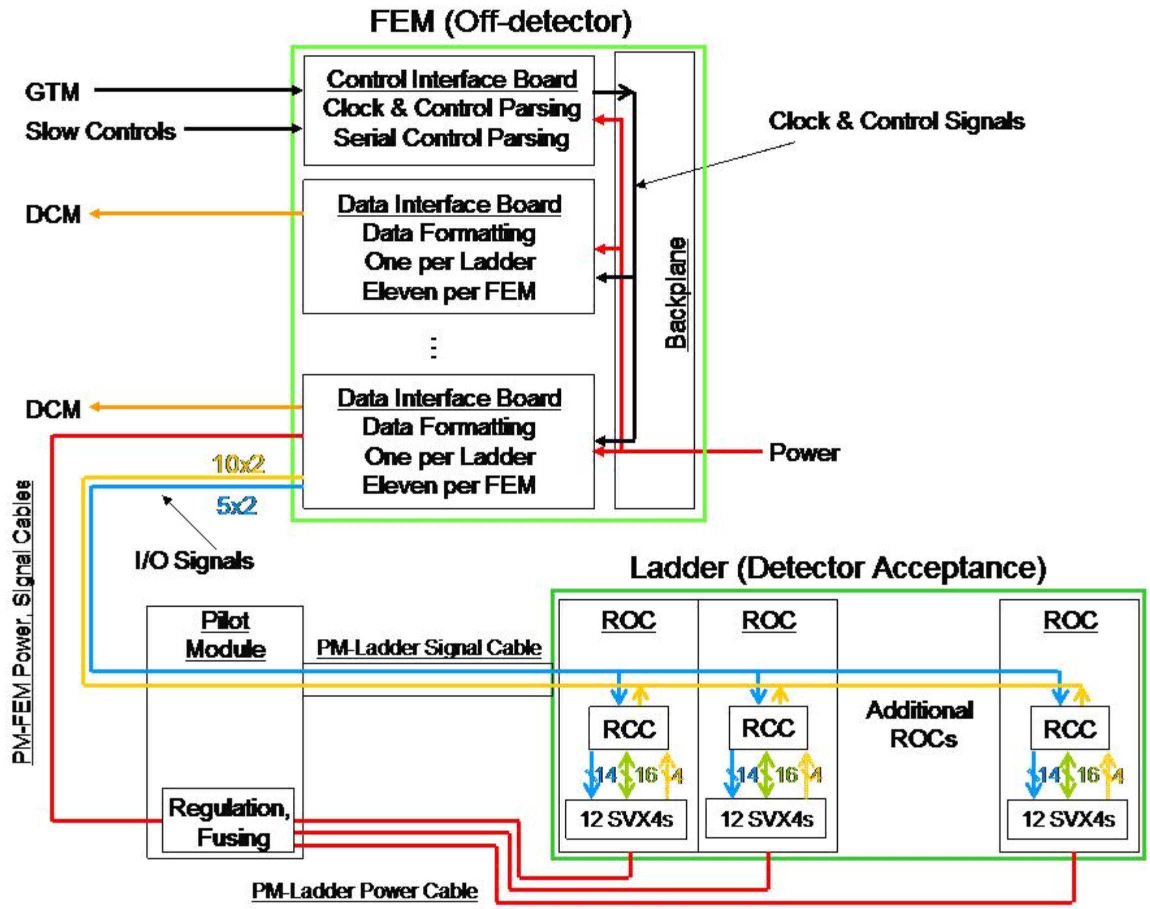

Figure 1: Schematic diagram of strip electronic system.

3.1.2. Responsibilities (using DOE construction funds unless otherwise specified)

- A contract for 400 silicon strip sensors has been placed with Hammatsu. This purchase is paid for by RIKEN. The contract requires the company to deliver sensors that meet our specifications, including passing Q/A tests. BNL, SUNY-SB, and University of New Mexico (UNM) will perform the final sensor Q/A before the sensors are wire-bonded to the ROCs.

- A sufficient number of SVX4 chips have been purchased using RIKEN funding. These chips have been tested at FNAL before delivery.
- The ROC's are being developed at ORNL. The manufacture of the cards will be overseen by ORNL, and all testing and Q/A will be performed at ORNL by ORNL and Iowa State University (ISU) personnel.
- The assembly of the strip sensors and the ROCs to sensor modules will be overseen by BNL personnel.
- The pilot modules will be jointly designed by ORNL and ISU. The assembly will be overseen by ORNL and Q/A performed at ORNL by ORNL and ISU personnel.
- The FEM's are being developed and tested at ORNL. The assembly will be overseen by ORNL and the Q/A performed by ORNL personnel.
- The DCMs will be designed, fabricated and tested at Nevis Laboratories, Columbia University, with Nevis personnel having responsibility for the delivery.
- Mounting and aligning the sensor modules on ladders, with signal and power connections ready for integration the VTX will be performed at BNL with BNL and SUNY-SB personnel working together, with overall responsibility BNL staff.
- Tests of strip detector ladders will take place at BNL with BNL, SUNY-SB, ISU, ORNL and UNM personnel, with overall responsibility by BNL staff.

3.2 PIXEL DETECTOR

The production and delivery of this detector is the responsibility of Japanese and French institutions within PHENIX. The pixel detector forms the inner two layers R1 and R2) of the VTX. It is constructed from individual pixel ladders. The number of ladders, channels per ladder is summarized in Table 3. Each pixel ladder is comprises of pixel sensors bump-bonded to read-out chips, two signal and power buses (one for each side), and a mechanical stave with cooling. The rest of the pixel system includes SPIRO modules to interface between the ladders and the off-detector front-end-modules (FEMs). Q/A procedures will be established by the Japanese institutions in collaboration with the US VTX project to insure that all pixel-ladders meet the design goals of the project.

Table 3: Summary of main parameters of the inner two VTX layers.

VTX	Layer	R1	R2
Geometrical dimensions	R (cm)	2.5	5
	Δz (cm)	21.8	21.8
	Area (cm^2)	280	560
Channel count	Sensor size R × z (cm^2)	1.28 × 1.36 (256 × 32 pixels)	
	Channel size	50 × 425 μm^2	
	ROCs/sensor module	4	
	Modules/ladder	4	
	Ladders	10	20
	Sensor modules	40	80
	Readout chips	160	320
	Readout channels	1,310,720	2,621,440

3.2.1 Definitions

- A silicon pixel sensor contains 4 matrixes of 32 by 256 pixels. Each pixel has size of 50μm × 425μm.
- The ALICE1LHCb readout chip (ROC) was developed at CERN for ALICE experiment of LHC. One ROC is bump-bonded tn one pixel matrix of the pixel sensor (i.e. 4 chips per sensor chip).
- A sensor module consists of a sensor chip bump-bonded with 4 read-out chips. This is the basic building block of the pixel system.
- A pixel bus is a thin, high density signal and power bus to read out the sensor module. It also supplies low voltage power to the read-out chips and bias voltage to the sensors.
- A bus extender is an extension of the pixel bus to a SPIRO module.
- A half ladder consists of two sensor modules, a pixel bus, and a bus extender. It is connected and is read-out by a SPIRO module. A half ladder+ SPIRO is a basic read-out unit of the system.
- A stave is a mechanical component that includes a support board (Carbon-Carbon thermal plate), the cooling tubes, and coupling system to the barrel mount.
- A pixel ladder consists of two half ladders mounted on a mechanical stave and is the basic building block of the pixel system. Pixel ladders are mounted on the barrel mounts.
- A Silicon Pixel Interface Read-Out (SPIRO) module supports the read out and control of the pixel ROCs in a half-ladder. It reads the data from the pixel ROCs, and sends the data to a FEM with high speed optical data link.
- A pixel Front End Module (FEM) serves as the interface between SPIRO modules and a DCM. A FEM supports and controls 2 SPIRO modules, formats the data from SPIRO, and sends the data to a DCM.

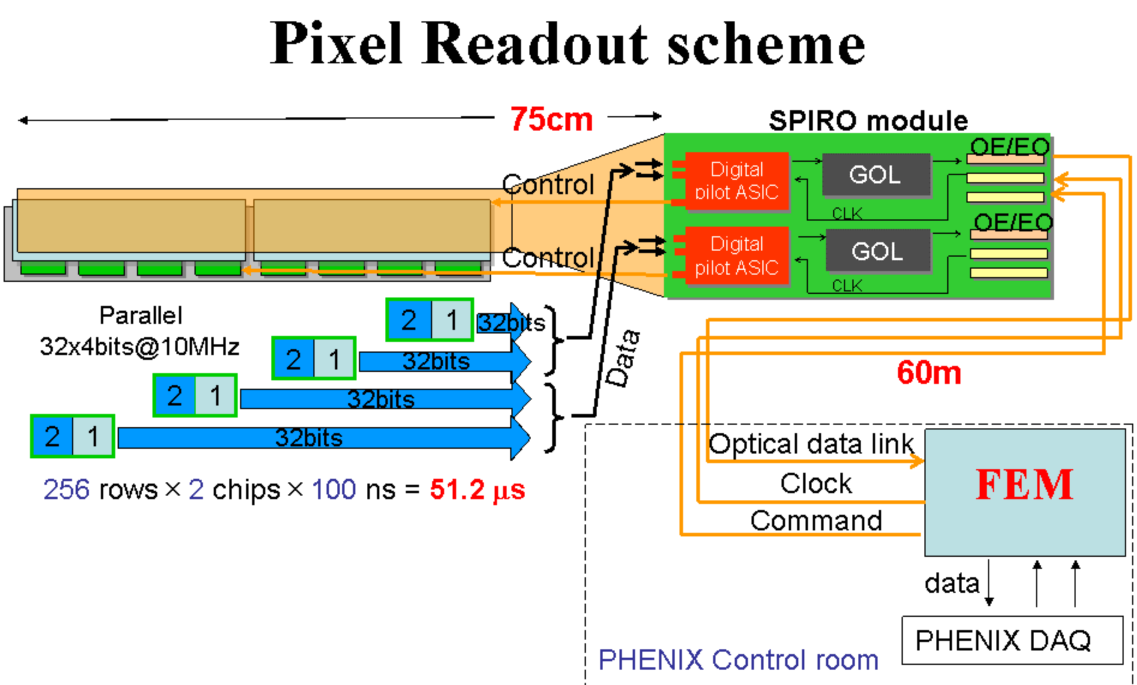

Figure 2: Schematic diagram of pixel electronic system

3.2.2 Responsibilities

- The pixel sensors have been purchased through CERN by RIKEN. All pixel sensors needed for the two pixel layers have been delivered to RIKEN.
- The pixel ROCs have been purchased by and delivered to RIKEN. RIKEN is responsible for the probing and Q/A of the ROCs. After the Q/A, the ROCs will be sent to a vendor in Finland (VTT) to be bump-bonded with the pixel sensors.
- VTT will bump bond the sensors and the read-out chips, and will deliver the sensor modules to RIKEN as specified in a contract between RIKEN and CERN. A minimum of 150 fully functional sensor modules will be delivered.
- The Q/A of the sensor modules is the responsibility of RIKEN
- The Pixel bus and the bus extender is the responsibility of RIKEN.
- The SPIRO module is the responsibility of Ecole Polytechnique (France).
- Assembly of the pixel ladders is the responsibility of RIKEN
- The design, fabrication, and the testing of the FEMs is the responsibility of Stony Brook University, with funding from RIKEN.
- DCM will be designed, fabricated, and tested at Nevis, with Nevis personnel having responsibility for the delivery of working modules.

3.3 MECHANICS and INFRASTUCTURE

The mechanical support system is comprised of ladder staves that provide support and cooling for each pixel or strip ladder, and an overall structure for supporting the ladders. The internal position tolerance for the ladders within the VTX is 25 microns. The cooling system will be capable of removing up to 3100 Watts of heat from the device and is required to operate in nominal operating temperature between 0^o and 20^o C. The whole VTX will be in a dry gas environment of N_2.

The infrastructure for the VTX includes power supplies, racks, cooling system, control and monitoring, mechanical support between the pole-tips as well as installation rigs.

3.3.1 Definitions

- A mechanical stave is a basic mechanical component that includes the omega-shaped structural support piece, cooling tube(s), board (C-C thermal plane), and coupling system to attach to the barrel mount. There are two kinds of staves, one for strips and one for pixel.
- A cooling tube is ductwork containing cooling fluid to remove heat generated by VTX electronics.
- A barrel mount is a “half-moon” shape structure that supports the ladders and connects them to the space frame. The staves will be pinned to the barrel mounts for indexing and alignment.
- The Space frame consists of two Graphite Fiber Reinforced Polymer (GFRP) halves that connect rigidly at the mid-plane and support the barrel detector half-cylinders via the barrel mounts.

- The Dry gas enclosure is the outer housing designed to prevent condensation on VTX electronics.
- The Cooling system comprises coolant, distribution system, controls and refrigeration. Baseline design calls for a single-phase coolant that is a fluorinert fluid.
- The Suspension system connects the VTX to mechanical support system.
- The mechanical support system is support beams for VTX between the PHENIX central magnet pole tips.
- Assembly and alignment fixtures are tools for fabrication of ladders. The fixtures align components (sensors, ROCs, stave, etc) of a ladder within the required mechanical tolerance and assemble them into a ladder.
- Power supply system includes all low voltage and bias voltage supplies and associated monitoring and control required for the VTX electronics.
- A new beryllium beam-pipe with a 4 cm inner diameter and with 500 μm nominal thickness will replace the existing larger beam pipe.

3.3.2 Responsibilities

- The design, prototyping, manufacturing of the mechanical staves, cooling tubes, barrel mounts, space frame, suspension system, dry gas enclosure, cooling system, and fixtures for assembly and alignment will be contracted out to a mechanical design/fabrication company. The VTX mechanical project engineer and VTX integration subsystem manager will have oversight of the work performed at this company.
- The mechanical support system for the VTX is the responsibility of the VTX integration sub-system manager. It will be paid for by the VTX project, but designed and construction overseen by staff in the PHENIX operations group in consultation with the VTX mechanical project engineer.
- The design and fabrication of the assembly and alignment fixtures is overseen by the VTX mechanical project engineer with the integration manager, the pixel manager, and the strip manager.
- The installation fixtures to support the VTX during installation are the responsibility of the VTX integration subsystem manager. It will be paid for by the VTX project, but designed and construction overseen by staff in the PHENIX operations group in consultation with the VTX mechanical project engineer.
- The infrastructure (racks, power, and cooling) for the power supply system, cooling system and the control systems to monitor operating conditions of the VTX is the responsibility of the VTX integration subsystem manager. It will be paid for by the VTX project, but designed and construction overseen by staff in the PHENIX operations group in consultation with the VTX mechanical and electrical project engineers.
- The power-supply systems for both the sensors and the read-out electronics is the responsibility of the VTX electrical project engineer. This work will be done in close collaboration with the strip and pixel subsystem managers. It will be paid for by the VTX project, but designed and construction overseen by staff in the PHENIX operations group.

- The design, fabrication, and installation of the beam-pipe is the responsibility of BNL and is not included in the scope of the VTX project.

3.4 SUMMARY of DELIVERABLES

The PHENIX VTX project will be complete when all component deliverables as specified in Table 4 have been assembled, tested, and received at BNL. In the "working spares" column there is a hierarchy, i.e. some of the spare sensor modules are used to construct the spare ladders, the rest are kept separate as stand-alone spares. Similarly the spare ROCs are used in two ways; those found in the spare modules (including those assembled in ladders), and some ROCs are kept as stand-alone spares.

Table 4 Component Deliverables of VTX

Item	**Number**	**Working Spares**
Strip system		
Strip ROCs	246	84 (66 in spare modules)
Sensor modules	246	66 (33 in spare ladders)
Strip ladders	44	6 (3 R3+3 R4 ladders)
Strip Pilot modules	44	5
Strip FEMs	44	5
Mechanical system		
pixel staves	30	10 (2 in assembled ladders)
strip staves	44	20 (6 in assembled ladders)
Barrel mounts	12	2
Space frame	1	0
Suspension system	1	0
Dry gas enclosure	1	0
Cooling system	1	Spare components available
Power supply system	1	Spare components available
DCM		
Strip DCMs	44	5
Pixel DCMs	30	3

Table 5 In kind contribution to the VTX from RIKEN and France group

Item	**Number in VTX**	**Working Spares**
Strip system		
Sensors	246	66 in sensor modules
SVX4	2952	1008 in spare ROCs
Pixel system		
Pixel ladders	30	2
SPIRO modules	60	6
Pixel bus	60	4
Pixel FEMs	30	3

4 MANAGEMENT ORGANIZATION

4.1 GENERAL

This document provides the proposed management organization and delineates responsibilities within the project. Figure 3 shows the proposed management structure for the PHENIX VTX construction project.

4.2 PROJECT MANAGEMENT RESPONSIBILITIES

4.2.1 DOE project management

The DOE Office of Nuclear Physics (NP) has overall DOE responsibility for the project. Jehanne Simon-Gillo is the Federal Program Manager for the project.

- Provides programmatic direction.
- Functions as DOE headquarters point of contact for the project.
- Budgets for funds to execute the project.
- Approves Level 1 baseline changes

Michael A. Butler is the Federal Project Officer at the Brookhaven Site Office (BHSO)

- Provides overall management oversight for the project.
- Submits key project documents to DOE and reports project progress.
- Approves Level 2 baseline changes
- Ensures that the project complies with applicable ES&H requirements.

4.2.2 BNL project oversight

The BNL project oversight manager is Thomas Ludlam, BNL.

<u>Responsibilities:</u>

The BNL project oversight manager will be administratively and fiscally responsible for the project. In particular he will:

- Provide overall management oversight for all aspects of the project.
- Approve key personnel appointments made by the project manager.
- Approve major subcontracts recommended by the project manager.
- Manage the distribution of contingency funds for the project.
- Ensure that the project has demonstrated that it meets the functional requirements.
- Review quarterly status reports.
- Schedule and organize external reviews of the project.
- Ensure the work is performed safely and in compliance with the ISM rules.

The BNL project oversight manager will keep the BNL management and the DOE informed about the technical goals and progress of the project. He will conduct periodic reviews to insure that the project continues to serve the long-term interests of the laboratory's research program through the related upgrades of the detectors and the RHIC collider.

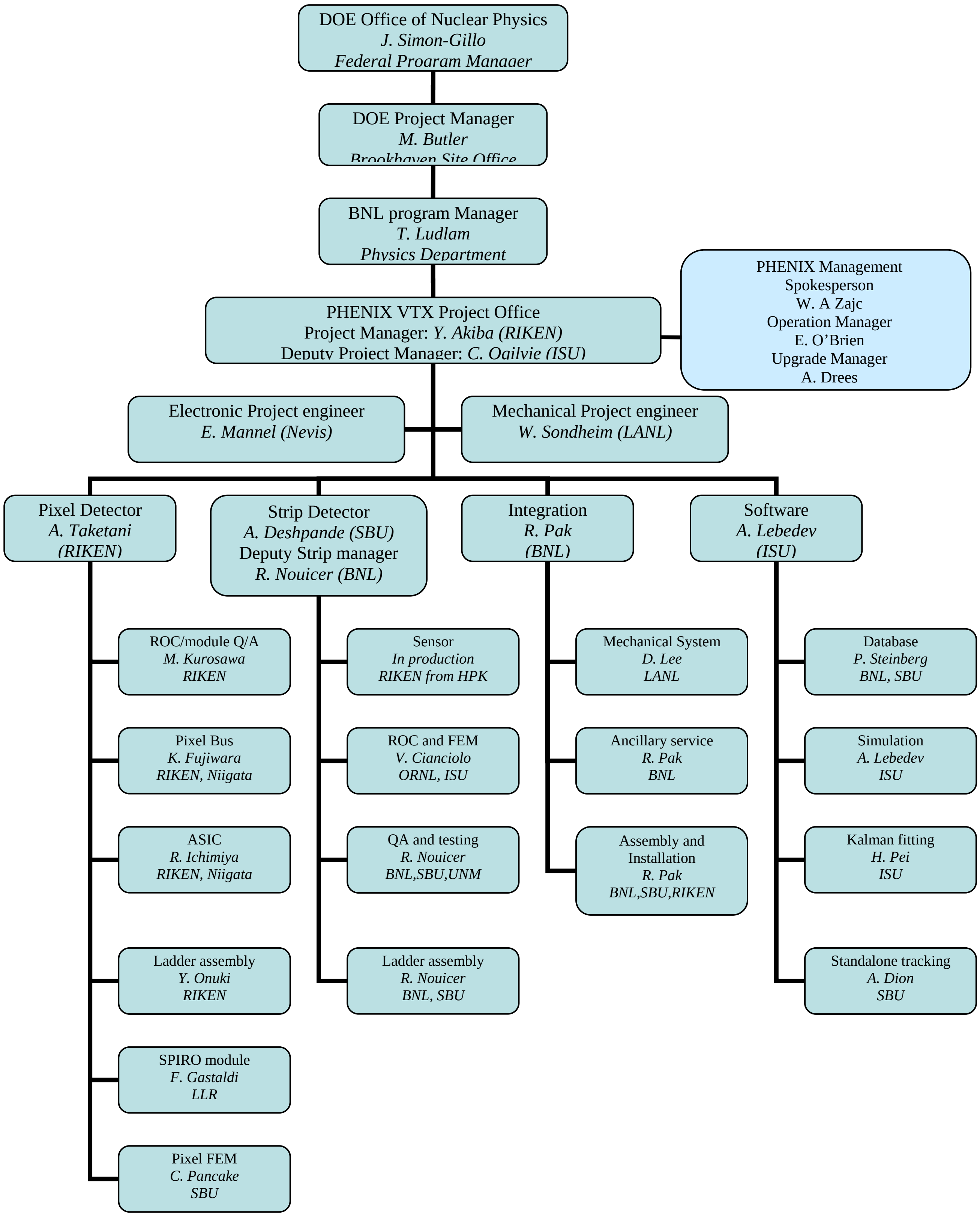

Figure 3. Management chart for the PHENIX VTX construction project.

4.2.3 PHENIX Collaboration Management

The PHENIX Collaboration Management has overall responsibility for the successful execution of the scientific operation of the PHENIX detector. William Zajc (Columbia) is the PHENIX Spokesperson. Axel Drees (Stony Brook) is the PHENIX Upgrades Manager, and has direct responsibility within PHENIX for oversight of the VTX project. Edward O'Brien (BNL) is the PHENIX Operations Manager, and has responsibility of the operation of PHENIX and for oversight of all subsystems/detectors in PHENIX. Don Lynch (BNL) is the chief engineer of the PHENIX and is responsible for the engineering and technical support. The PHENIX Management is responsible for the integration of the VTX detector into PHENIX, and provides the technical support for the commissioning and operation of the completed detector. The PHENIX Management reviews and approves any changes to the baseline performance parameters of the VTX.

4.2.4 Project management office

The VTX project office consists of the project manager and the deputy project manager, along with the project electrical and mechanical engineers. In general, the project manager is responsible for the scientific management of the project, the deputy project manager is responsible for the delivery of the DOE portion of the VTX, and the project engineers are responsible for the electrical and mechanical oversight of both the strip and pixel subsystems.

The full VTX project office will meet regularly as a group as well as with the PHENIX management to assure that the project meets the performance and budget goals.

The project manager is Yasuyuki Akiba, RIKEN.

<u>Responsibilities</u>

The project manager reports to the BNL project oversight manager. The project manager will have the following responsibilities:

- Responsible and accountable for the successful execution of the project.
- Delivers project deliverables.
- Keeps the PHENIX management and Executive council informed on the progress of the project.
- With the project engineers and PHENIX operations manager, ensures that the project integrates properly into the PHENIX detector and with existing subsystems.
- Identifies and ensures timely resolution of critical issues.
- Allocates funds with deputy project manager with consultation with subsystem managers.
- Allocates the contingency funds following approved procedures.
- Appoints subsystem managers with the approval of PHENIX management.
- Organizes and holds regular meetings (weekly and quarterly) of the VTX group, with the deputy project manager.
- Chair the VTX group meetings.
- Submits quarterly status reports, with the deputy project manager.

- Ensures the work is performed safely and provides necessary ES&H documentation, with the deputy project manager and PHENIX safety manager.
- Responsible with the project engineers and subsystem managers for the technical direction of the project.
- Controls changes in the system design requirements, including interfaces between subsystems, with the project engineers.
- Responsible with the deputy project manager and subsystem managers for providing documentation and presentations for project reviews.
- Responsible with the deputy project manager and subsystem managers for developing and maintaining project documentation meeting PHENIX documentation standards.

The deputy project manager is Craig Ogilvie, Iowa State University.

<u>Responsibilities</u>
The deputy project manager and the project manager report to the BNL project oversight manager. The deputy project will have the following responsibilities:

- With the project manager, responsible and accountable for the successful execution of the project.
- Under the direction of the project manager, delivers project deliverables.
- Supervises the electrical and mechanical project engineers.
- Implements a performance measurement system.
- Develops functional requirements with the project engineers and subsystem managers.
- Identifies and ensures timely resolution of critical issues.
- Chair the VTX group meetings when the project manager is not available.
- Develops with the subsystem managers quarterly status reports. The report includes time schedule and spending report.
- Ensures the work is performed safely and provides necessary ES&H documentation, with the PHENIX safety manager.
- Responsible with the project manager and subsystem managers for providing documentation and presentations for project reviews.
- Responsible with the project manager and subsystem managers for developing and maintaining project documentation meeting PHENIX documentation standards.

The electronic project engineer is Eric Mannel, Columbia University.

<u>Responsibilities</u>

- Responsible for electronic integration of the VTX detector into PHENIX.
- Provides electrical oversight for the pixel and strip subsystems.
- Responsible with the subsystem managers for developing and maintaining the documentation of the electronics and electric system meeting PHENIX documentation standards.

- Approves with subsystem managers Q/A procedures and benchmarks for components before they are assembled into ladders.
- Approves with subsystem managers Q/A procedures and benchmarks for assembled ladders.
- Responsible for grounding plan and implementation.
- Responsible for power supply system.
- Under the direction of the project and deputy project managers, delivers project deliverables.
- Identifies and ensures timely resolution of critical issues.
- Responsible with the project and deputy project managers for providing documentation and presentations for project reviews.

The mechanical project engineer is Walter Sondheim, LANL.

Responsibilities

- Together with the integration subsystem manager, responsible for mechanical integration of the VTX detector with PHENIX.
- Develops with the integration subsystem manager the specifications of the VTX, including position requirements and cooling requirements.
- Responsible for oversight of external contractors for procurement of mechanical components.
- Provides mechanical oversight for each of the pixel and strip subsystems.
- Responsible with the subsystem managers for developing and maintaining the documentation of the mechanical system meeting PHENIX documentation standards.
- Develops with subsystem managers assembly and alignment procedures for assembling components into ladders.
- Approves with subsystem managers Q/A procedures and benchmarks for assembled ladders.
- With the project and deputy project managers, delivers project deliverables.
- Identifies and ensures timely resolution of critical issues.
- Responsible with the project and deputy project managers for providing documentation and presentations for project reviews.

4.2.5 Subsystem managers

Each of subsystem managers is responsible for one of the four major subsystems: strip detector, pixel detector, integration, and software. The subsystem managers and deputy subsystem managers are:

- Pixel detector: Atsushi Taketani (RIKEN)
- Strip detector: Abhay Deshpande (Stony Brook) and Rachid Nouicer (deputy, BNL)
- Integration: Robert Pak (BNL)
- Software: Alexandre Lebedev (ISU)

The subsystem managers report directly to the VTX project office and will be responsible for the design, construction, installation, and testing of their subsystem in accordance with the performance requirements, schedule, and budget.

<u>Responsibilities for subsystem managers</u>

- Assemble the staff and resources needed to complete the subsystem in collaboration with the project and deputy project managers
- Develop and follow the system design requirements
- Ensure that subsystems meet the system design requirements, including interfaces
- Responsible for carrying out the design, construction and assembly of the subsystem in accordance with the scope, schedule and budget
- Provide monthly reports on the status of the subsystem to the deputy project manager
- Ensure the work is performed safely and provide necessary ES&H documentation
- Responsible with the project and deputy project managers for providing documentation and presentations for project reviews
- Develop and maintain the documentation of the subsystem.

In addition to these general responsibilities, each subsystem managers has the following specific responsibilities:

Pixel detector manager:

- Liaison with vendor for bump-bonding
- Liaison with vendor for bus-production

Strip detector manager:

- Liaison with vendor for sensor production
- Liaison with FNAL for SVX4

Integration manager:

- Liaison, together with David Lee, LANL, with mechanics vendor
- Liaison with C-AD department at RHIC
- Liaison, together with VTX mechanical project engineer, with PHENIX project and safety engineers

Software manager

- Liaison with PHENIX offline and online software management

5 Schedules and Budget

The PHENIX VTX project has been organized into a work breakdown structure (WBS) for purposes of planning, managing and reporting project activities. Work elements are defined to be consistent with discrete increments of project work.

Figure 4 is a Gantt chart of the project schedule, consistent with the WBS. The project begins in first quarter FY07 and ends in 3rd quarter FY09. The full barrel VTX system is installed and ready for beam by June 2009.

The RIKEN milestones lie within the Pixel WBS task 1.1.2.

5.1 Schedule

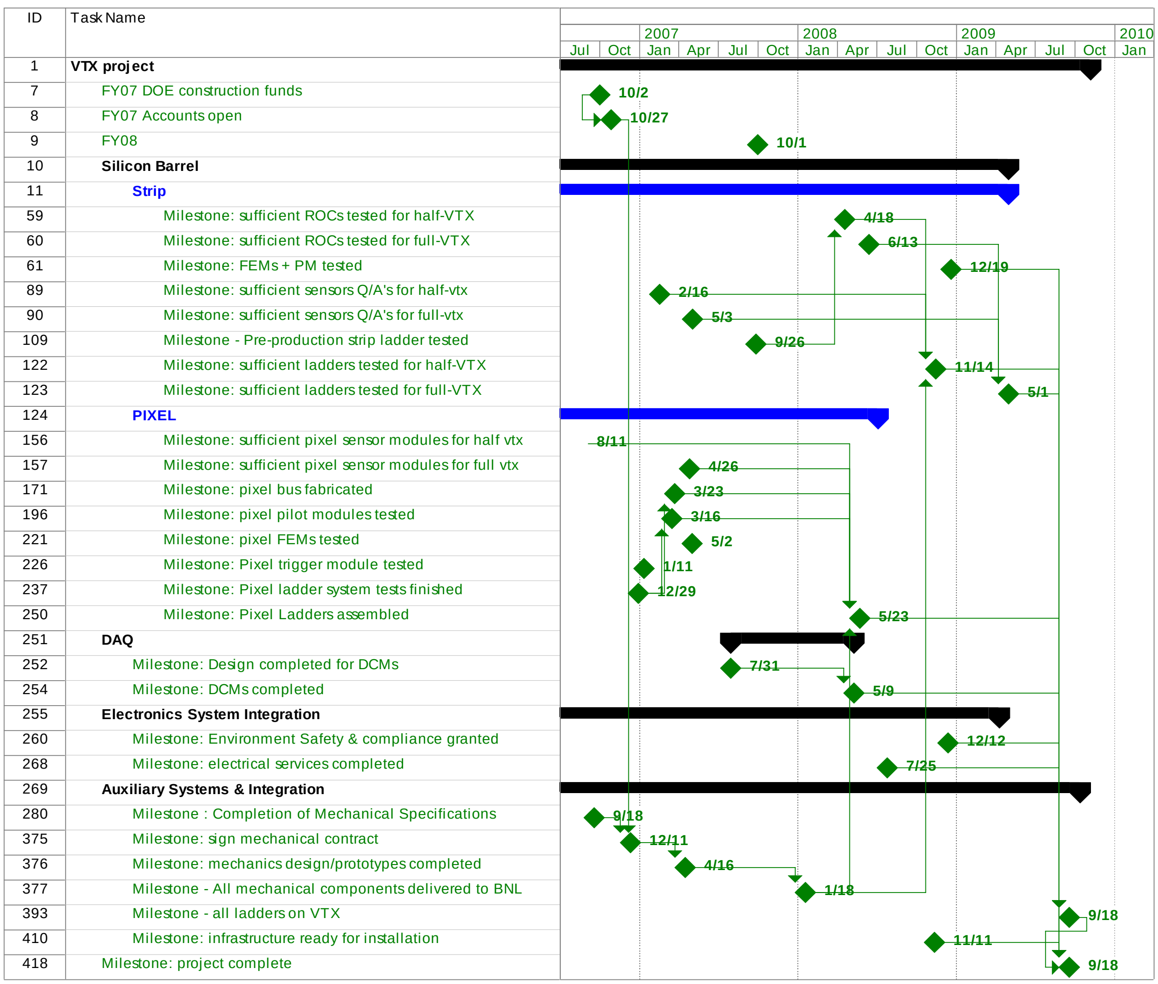

Figure 4. High level schedule of the PHENIX VTX construction project.

5.1 Control Milestones

Table 6 shows the project management and control milestones ordered by WBS and table 7 shows the same information ordered by date. Items in italics (blue) are the responsibility of the RIKEN/French groups.

Table 6 Control Milestones of the project ordered by WBS number.

WBS	Milestone	Quarter
1	VTX project	
	FY07 DOE construction funds	FY07 1Q
	FY07 Accounts open	FY07 1Q
	FY08	FY08 1Q
1.1	Silicon Barrel	
1.1.1	Strip	
	Milestone: sufficient ROCs tested for half-VTX	FY08 3Q
	Milestone: sufficient ROCs tested for full-VTX	FY08 3Q
	Milestone: FEMs + PM tested	FY09 1Q
	Milestone: sufficient sensors Q/A's for half-vtx	FY07 2Q
	Milestone: sufficient sensors Q/A's for full-vtx	FY07 3Q
	Milestone - Pre-production strip ladder tested	FY08 1Q
	Milestone: sufficient ladders tested for half-VTX	FY09 1Q
	Milestone: sufficient ladders tested for full-VTX	FY09 3Q
1.1.2	*PIXEL*	
	Milestone: sufficient pixel sensor modules for half vtx	*FY06 4Q*
	Milestone: sufficient pixel sensor modules for full vtx	*FY07 3Q*
	Milestone: pixel bus fabricated	*FY07 2Q*
	Milestone: pixel pilot modules tested	*FY07 2Q*
	Milestone: pixel FEMs tested	*FY07 3Q*
	Milestone: Pixel trigger module tested	*FY07 2Q*
	Milestone: Pixel ladder system tests finished	*FY07 2Q*
	Milestone: Pixel Ladders assembled	*FY08 3Q*
1.2	DAQ	FY07 4Q
	Milestone: Design completed for DCMs	FY07 4Q
	Milestone: DCMs completed	FY08 3Q
1.3	Electronics System Integration	
	Milestone: Environment Safety & compliance granted	FY09 1Q
	Milestone: electrical services completed	FY08 4Q
1.4	Auxiliary Systems & Integration	
	Milestone : Completion of Mechanical Specifications	FY06 4Q
	Milestone: sign mechanical contract	FY07 1Q
	Milestone: mechanics design/prototypes completed	FY07 3Q
	Milestone - All mechanical components delivered to BNL	FY08 2Q
	Milestone - all ladders on VTX	FY09 4Q
	Milestone: infrastructure ready for installation	FY09 1Q
	Milestone: project complete	FY09 4Q

Table 7 Control Milestones of the project ordered by date.

Milestone	Quarter
Milestone: sufficient pixel sensor modules for half vtx	*FY06 4Q*
Milestone : Completion of Mechanical Specifications	FY06 4Q
FY07 DOE construction funds	FY07 1Q
FY07 Accounts open	FY07 1Q
Milestone: sign mechanical contract	FY07 1Q
Milestone: sufficient strip sensors Q/A's for half-vtx	FY07 2Q
Milestone: pixel bus fabricated	*FY07 2Q*
Milestone: pixel pilot modules tested	*FY07 2Q*
Milestone: Pixel trigger module tested	*FY07 2Q*
Milestone: Pixel ladder system tests finished	*FY07 2Q*
Milestone: sufficient strip sensors Q/A's for full-vtx	FY07 3Q
Milestone: sufficient pixel sensor modules for full vtx	*FY07 3Q*
Milestone: pixel FEMs tested	*FY07 3Q*
Milestone: mechanics design/prototypes completed	FY07 3Q
Milestone: Design completed for DCMs	FY07 4Q
FY08	FY08 1Q
Milestone: Pre-production strip ladder tested	FY08 1Q
Milestone: All mechanical components delivered to BNL	FY08 2Q
Milestone: sufficient ROCs tested for half-VTX	FY08 3Q
Milestone: sufficient ROCs tested for full-VTX	FY08 3Q
Milestone: Pixel Ladders assembled	*FY08 3Q*
Milestone: DCMs completed	FY08 3Q
Milestone: electrical services completed	FY08 4Q
Milestone: Strip FEMs + PM tested	FY09 1Q
Milestone: sufficient strip ladders tested for half-VTX	FY09 1Q
Milestone: Environment Safety & compliance granted	FY09 1Q
Milestone: infrastructure ready for installation	FY09 1Q
Milestone: sufficient strip ladders tested for full-VTX	FY09 3Q
Milestone: all ladders on VTX	FY09 4Q
Milestone: project complete	FY09 4Q

5.2 BUDGET

Figure 4 shows the cost summary for the VTX project in FY06 dollars and the required annual funding profile in at-year (AY) dollars.

5.2.0 Contingency

The project manager manages the contingency funds according to the approved procedures. Contingency is allocated under the change control procedures described in the next section. The average contingency is 26%. This section describes how the contingency for a given WBS element is to be calculated. If the Project Manager or

Subsystem Manager decides these factors are not appropriate, this must be documented in the cost book.

Risk is a function of the following factors: the sophistication of the technology, the maturity of the design effort, the accuracy of the cost sources and the impact of delays in the schedule. Risk analysis is performed for each WBS element at the lowest level estimated. Results of this analysis are related to a contingency which is listed for each WBS element. The goal is to make the method of contingency determination as uniform as possible for all project WBS elements.

Definitions

Base Cost Estimate – The estimated cost of doing things correctly the first time. Contingency is not included in the base cost.

Cost Contingency – The amount of money, above and beyond the base cost, that is required to ensure the project's success. This money is used only for omissions and unexpected difficulties that may arise. Contingency funds are held by the Project Manager. The contingency % is calculated for each WBS item as

$$\text{Cont \%} = \text{technical risk factor} \times \text{Base\%} + \text{cost risk factor} \times \text{Base\%} + \text{schedule risk factor} \times \text{Base\%}$$

For the majority of the project, Base%=7.5%, the exception is the strip FEE cost estimates where the Base% is evaluated for different items and ranges from 4 to 10%.

Risk Factors

Technical Risk – Based on the technical content or technology required to complete the element, the technical risk indicates how common the technology is that is required to accomplish the task or fabricate the component. If the technology is so common that the element can be bought "off-the-shelf", i.e., there are several vendors that stock and sell the item, it has very low technical risk, therefore a risk factor of 1 is appropriate. On the opposite end of the scale are elements that extend the current "state-of-the-art" in this technology. These are elements that carry technical risk factors of 4. Between these are: making modifications to existing designs (risk factor 1.5), creating a new design which does not require state-of-the-art technology (risk factor 2, and creating a design which requires R&D, and advances the state-of-the-art slightly (risk factor 3).

Cost Risk – Cost risk is based on the data available at the time of the cost estimate. It is subdivided into 4 categories.

The first category has a risk factor between 1 and 2. It includes elements for which there is a recent price quote from a vendor or a recent catalog price. If the price of the complete element, or the sum of its parts, can be found in a catalog, the appropriate risk factor to be applied is 1. If there is an engineering drawing or specification for the element, and a reliable vendor has recently quoted a price based on these, the cost risk factor to be applied is between 1 and 2.

The second category has a risk factor of 2. It includes elements for which there exists some relevant experience, e.g. if the element is similar to something done previously with a known cost, or if the element is something for which there is no recent experience, but the capability exists.

The third category has a risk factor of 3. It includes is for elements for which there is information that, when scaled, can give insight into the cost of an element or series of elements.

The fourth category has a risk factor of 4. It includes is for elements for which there is an educated guess, using the judgment of engineers or physicists.

Schedule Risk – If a delay in the completion of the element could lead to a delay in a critical path or near critical path component, the schedule risk is 3. If a delay in the completion of the element could cause a schedule slip in a subsystem which is not on the critical path, the schedule risk is 2. Only elements where a delay in their completion would not affect the completion of any other item have schedule risks of

Table 8. The cost summary for the PHENIX VTX construction project. Amounts are in FY07 kilo-dollars.

WBS	Name	Material k$	Manpower k$	BNL Transfer k$	Contingency %	Contingency k$	TEC k$	Preops k$	TPC k$
1	VTX project	1,522	1,824	195	26	912	4,455	105	4,560
1.1.1	Strip	624	740	5	26	360	1,730	0	1,730
1.1.1.1	Strip FEE	494	631	0	24	267	1,393	0	1,393
1.1.1.2	Strip Sensor	29	0	2	29	9	40	0	40
1.1.1.3	Strip System test	9	24	0	42	14	47	0	47
1.1.1.4	Assembly and Testing of Strip ladders	92	85	4	39	70	250	0	250
1.2	DAQ	99	30	23	25	38	191	0	191
1.3	Electronics System Integration	139	348	59	21	116	662	0	662
1.3.1	electronics oversight	0	330	59	18	71	460	0	460
1.3.3	Electronic Services	139	18	0	29	45	202	0	202
1.4	Auxillary Systems & Integration	660	652	98	27	386	1,796	0	1,796
1.4.2	Mechanical Structure	511	247	94	31	264	1,116	0	1,116
1.4.3	Assembly of ladders onto barrel	39	30	4	30	22	95	0	95
1.4.4	Infrastructure	110	108	0	23	51	269	0	269
1.4.5	Mechanical system Integration	0	267	0	18	49	315	0	315
1.5	Management	0	55	10	18	12	77	0	77
1.6	Installation	0	0	0	30	0	0	105	105

Table 9. The budget Profile of the VTX Project. An inflation rate for 2% for material and 4% for manpower is assumed in the AY dollars.

WBS	Name	TPC		FY07 AY k$	FY08 AY k$	FY09 AY k$	FY10 AY k$	TPC AY k$
1	VTX project	4,560		1,990	2,027	554	95	4,666
1.1.1	Strip	1,730		718	920	128	0	1,766
1.2	DAQ	191		0	195	0	0	195
1.3	Electronics System Integration	662		173	404	106	0	683
1.4	Auxiliary Systems & Integration	1,796		1,070	475	281	0	1,826
1.5	Management	77		29	33	18	0	80
1.6	Installation	105		0	0	21	95	116

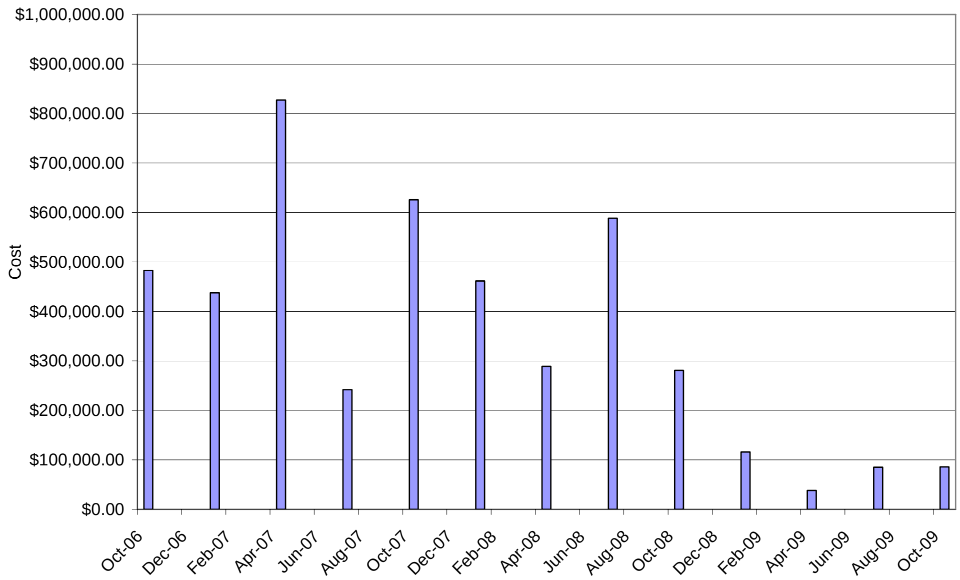

Figure 5. TPC per quarter of the VTX project in FY07 dollars

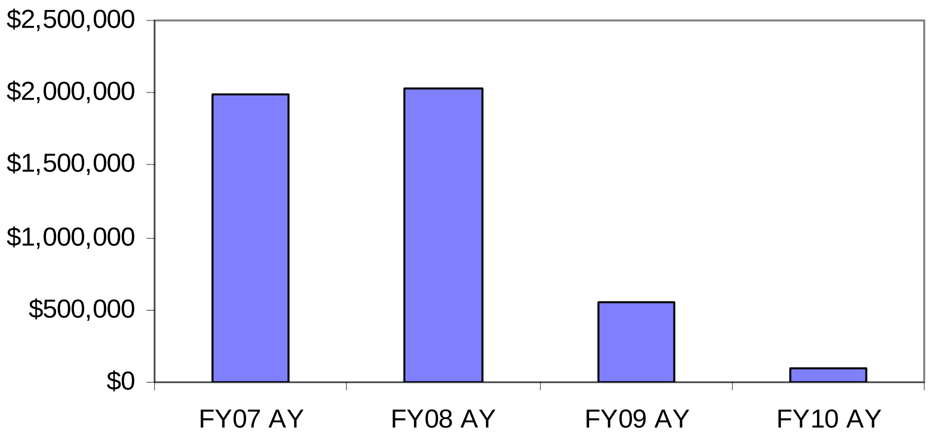

Figure 6 TPC per year in at year (AY) dollars

6 CHANGE CONTROL

All changes to the technical, cost and schedule baselines shall be identified, controlled, and managed through a traceable, documented change control process, which will have been approved. Changes to the technical, cost and schedule baselines will be controlled using the thresholds described in Table 9.

It is expected that over the term of the VTX construction project the design or definition of components will evolve. When components of a system of the complexity of the VTX detector change without a system of checks and balances, confusion may occur; this would affect the technical, cost or schedule outcome of the VTX construction project. The following Change Control Procedure is designed to control this natural evolution and is intended to reduce or eliminate change as a source of problems.

Items that fall under this Change Control Procedure include the following:

VTX Engineering Drawings and Schematics with revision “A” or higher.
Controlled VTX Notes with revision “A” or higher.
Statements of Work.
Specifications.
Memorandum of Understanding.
Requirements Documents.
Lists of Deliverables.
WBS Dictionary.
Project Schedule.
Interface/Integration Specifications.
Integration Envelopes.
Documented Work Procedures.
Rigging Procedures.
Operations Procedures.
VTX Detector Baseline Configuration.

All changes are reportable to the VTX Project Management Office for tracking, but it is only Levels 1, 2, & 3 which requires project office approval. Changes which only affect a single subsystem; do not impact the subsystems interfaces, overall performance, cost, or schedule goals, will be managed and controlled by the subsystem managers. Level 1, 2, &3 changes will possess one or more of the following attributes:

- Physical interface: the envelope within which the element will be contained.
- Utilities interface: the location, size, and rate of “flow” of utilities supplied.
- Signal interface: the location, number and size of input/output signal cabling.
- Structural interface: the location, number, shape, size, hole pattern, etc., of the element component from which the subsystem is supported or aligned.
- Parameters, function, and requirements which are used to define the technical scope and specification of the element component.
- Significant cost or the possibility of affecting the subsystem delivery schedule.

Table 10 defines the three categories of changes and the method of review and approval level required for each.

Table 10 Change approval levels

Level	Cost, Schedule, and Technical Impact	Review/Approval
1	Deviation from total project cost or cumulative allocation of contingency > $500k; WBS level 3 milestone delay >3-months; Technical deviation that significantly impacts other subsystems or baseline performance parameters.	DOE NP Program Manager, PHENIX Management, BNL Management, VTX Project Office
2	Deviation from Level-2 project cost or cumulative allocation of contingency > $250k; WBS level 3 milestone delay >2-months; Technical deviation with impact on other subsystems but doesn't affect baseline performance parameters.	DOE BHSO Federal Project Officer, PHENIX Management, BNL Management, VTX Project Office
3	Deviation from Level 2 project cost or cumulative allocation of contingency > $50k; WBS level 3 milestone delay >1-month; Technical deviation with minor impact on other subsystems and doesn't affect baseline performance parameters.	VTX Project Office

7 RISK

The project manager and the deputy project manager will mitigate risk through routine monitoring of the progress and performance of the project, including weekly VTX teleconferences, quarterly full-day VTX meetings, bi-weekly meetings of the subsystem managers and monthly meetings with PHENIX and BNL management. The final responsibility for risk management will rest with the project and deputy project managers. However, effective risk management requires the involvement of all project members.

The risks associated with the pixel sensors and readout electronics are estimated to be low since we use the ROCs and sensors developed at CERN and successfully used by a fixed target heavy-ion experiment (NA60). Bump-bonding of the ROCs to the sensors was one of the technical challenges, but the production yield of the process for the ALICE pixel detector is now at satisfactory level. There had been a moderate risk associated with the development of the pixel bus which we have been mitigating through a program of prototypes and system tests. A manufacturer of the bus we work with now has produced fine pitch pattern required for the pixel bus. First prototype half-ladders, consisting of two pixel sensor modules, a prototype pixel bus, and a prototype bus extender, have been made. The first prototype of SPIRO module and the pixel FEMs have been developed and they are now being tested. The largest known source of risk in the pixel read-out chain is the "pilot" ASIC used in SPIRO module. We have modified the digital pilot chip to meet our data taking speed requirement. The modified chip is used in the prototype SPIRO, and we are evaluating the chip itself and in the prototype SPIRO modules. There is a moderate to high integration risk which we are mitigating by preparing the first chain test of the half-ladder + SPIRO + FEM chain.

The risks associated with the strip read-out chip are low. We use a mature read-out chip, SVX4, developed at FNAL/LBL. The Q/A results of the SVX4 chips at FNAL show a satisfactorily high yield of good chips, and we have purchased sufficient number of SVX4 chips from FNAL. For the strip-pixel sensors, Hamamatsu produced pre-production stripixel sensors more than a year ago, and we have developed Q/A procedures for the sensors at BNL. The radiation tolerance of the sensors is a moderate risk over the lifetime of the operation of the VTX. The prototypes show an increase in leakage current at the rate documented for similar sensors, but this rate would mean that the leakage current would increase to within a factor of two of the maximum operating values during RHIC_II. Half of the expected dosage comes from a full-luminosity RHIC-II 500 GeV proton-proton run (3 fb^{-1}). We are mitigating the risk by quantifying the radiation levels in the PHENIX IR and by measuring the radiation tolerance of the sensors.

The first prototype detector made of the pre-production strip sensor and the first prototype ROC using SVX4 chip was successful. We have a good S/N ratio (~20 for a MIP equivalent signal) from the prototype detector. However, in the final ROC the S/N can be reduced due to the noise from the ROC itself since the ROC and the sensor is very close proximity, and this is the largest technical risk associated with the ROC. In order to mitigate this risk, we are now developing the second round prototype ROC which has the same form factor as the final ROC. We will perform system tests in the same ROC-sensor configuration as the final detector. We also schedule another design and prototyping round (Pre-production) after these tests. There is also a moderate integration risk, which we are reducing by assembling 6 prototype sensor modules, corresponding to one complete R4 ladder, into a telescope and test with cosmic rays and/or test beam.

The design of the mechanical system is not as advanced as the pixel and strip detectors. However, the risk associated with the mechanical system is estimated to be moderate since we will use a design, analysis, and engineering firm, HYTEC, which has ample experience and expertise on the design of silicon detector mechanics and similarly challenging mechanical system project, including work for ATLAS silicon tracker. The largest risk is that changes in specifications of the ladders could force a redesign of the mechanics. We are mitigating this risk by scheduling a 2nd round of specifications to take place after the pixel and strip system tests. This is designed to be the final sign-off from the VTX collaboration on the specifications. The cost of the mechanical system has been estimated by HYTEC. We have started design R&D of the mechanical system of VTX with HYTEC with our mechanical project engineer having close oversight of their work. In addition, HYTEC reports their progress in regular meetings with the VTX project.

The remaining system and the infrastructure consist of a mix of conventional and commercially available components, with low risks. The highest risk item is the custom installation rigging and support structure from the IR. We are mitigating this risk by having these items designed by the chief PHENIX mechanical engineer.

8 ASSESSMENTS

8.1 ENVIRONMENT, SAFETY AND HEALTH

8.1.0 Integrated Safety Management Plan

Environment, safety and health (ES&H) will be integrated into all phases of planning and implementation through to the final design and production processes of the project. The project engineers and mechanical subsystem managers will interface through the PHENIX safety manager to BNL C-AD safety management. The project will conform to BNL's Integrated Safety Management policies.

8.2 QUALITY ASSURANCE

"Quality" is defined as the "fitness of an item or design for its intended use" and Quality Assurance (QA) as "the set of actions taken to avoid known hazards to quality and to detect and correct poor results." The project and deputy project managers will work with the subsystem managers and PHENIX operations management to assure that performance goals are met.

9 PROJECT CONTROLS AND REPORTING SYSTEMS

Technical performance will be monitored throughout the project to insure conformance to approved functional requirements. Design reviews and performance testing of the completed systems will be used to ensure that the equipment meets the functional requirements. For each main system of the VTX project: there will be the following reviews:

- Design review including detailed concept for the system, detailed cost and schedule.
- Pre-production review, all details settled. A small number of units will be produced and tested, and the performance reported.
- Final design review, final cost and schedule, production QA and testing procedures.
- PHENIX and BNL safety reviews.
- PHENIX operations readiness review.

Technical information concerning the project that is of interest to the VTX collaboration and the PHENIX collaboration will be published and archived in the existing PHENIX Technical Note system. In general PHENIX Technical Notes are documents about a topic of a technical subject. These documents should be of an archival nature. PHENIX Technical Notes concerning VTX can document requirements, specifications, procedures or policies, and are controlled and approved by the VTX Project Office. The reason for issuing a PHENIX Technical Note is to insure that members of the collaboration and project are aware of its content and are made aware of changes when they occur. Practically this is accomplished by the project office announcing to the collaboration/project that a new PHENIX Technical Note has been issued.

10 INSTITUTIONAL PARTICIPATION

At this point, 20 institutions participate in the VTX project. The institutions and their anticipated project responsibilities are listed in Table 11.

Table 11. VTX Project Institutional Participation

Institution	**Project Responsibility and participation**
Brookhaven National Laboratory (BNL chemistry, BNL physics, and BNL Instrumentation Division)	Database software Detector infrastructure Strip sensor Strip detector Q/A, testing, assembly VTX detector assembly VTX detector integration to PHENIX E,S,H&Q
Charles University (Czech)	Pixel testing, software
Columbia University	VTX detector electrical integration Oversight of electrical system DCM
Ecole Polytechnique (France)	SPIRO module
Florida State University	Simulation study
Iowa State University	Project management Software Strip FEM
Institute of Physics, Academy of Science, Prague (Czech)	Pixel testing, software
KEK (Japan)	Pixel assembly
Kyoto University (Japan)	Simulation study
Los Alamos National Laboratory	Mechanical system Oversight of the mechanical system
Niigata University (Japan)	Pixel bus, Pixel Q/A and testing
OakRidge National Laboratory	Strip ROC, strip FEM
RIKEN (Japan) and RBRC	Project management Pixel ASIC, Pixel Q/A and testing Pixel bus, Pixel assembly Strip sensor, SVX4 chip
Rikkyo University (Japan)	Strip sensor testing
Stony Brook University	Pixel FEM Strip detector Q/A, testing, assembly
Tokyo Institute of technology (Japan)	Pixel Q/A and testing
University of New Mexico	Strip Q/A and testing