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Detector Systems Product Quality Control Plan

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REVISION HISTORY

Revision #	Effective Date	Additional Reviewers	Summary of Change
00			Initial release.

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LIST OF ACRONYMS

BNL	Brookhaven National Laboratory
EIC	Electron-Ion Collider
FRD	Functional Requirements Document
GRD	General Requirements Document
JLAB	Thomas Jefferson National Accelerator Facility
MIP	Manufacturing Inspection Plan
PRD	Performance Requirements Document
QC	Quality Control

Detector Systems Product Quality Control Plan

1. BACKGROUND & PURPOSE

Product Quality Control Plans (PQCPs) are required by the EIC Requirements Management Plan and are used to ensure that a system or deliverable will satisfy all pertinent requirements and specifications. The PQCP will define the processes used to confirm that requirements are communicated and verified throughout the design, development, acquisition, manufacturing and testing phases of the project.

Development of the Product Quality Control Plan also provides a framework for team members to identify activities and processes that require further definition, or are unclear within the context of a diverse working group that spans multiple organizations.

The plan should be developed in accordance with the requirements of the EIC Project Plans and Documents referenced in Table 1.

Table 1. EIC Project Plans and Documents

Document Name	Document Number
Integrated Safety Management Plan (ISMP)	add document number
Global Requirements Document (GLRD)	add document number
Requirements Management Plan (RMP)	
Interface Management Plan (IMP)	add document number
EIC Codes of Record	EIC-ORG-RSI-026
Configuration Management Plan	add document number
EIC Quality Assurance Plan	EIC-QAG-PLN-002

1.1. Responsibilities

Per the EIC Quality Assurance Plan, EIC Level 2 Managers (L2Ms, also referred to as System Managers) are responsible for implementing the requirements established in this QA Plan within their project system and subsystems.

Per the Quality Assurance Plan, L3 Managers are responsible for developing Quality Control (QC) Plans for their areas of responsibility and are to ensure that:

- the plans are available and controlled,
- teams are working in accordance with the plans, and
- plans are review at an adequate frequency to identify need for change, or to support advance planning of acquisitions and procurements (whether tangible or services, like designs) from other providers (Vendors, In-Kind Contributors, Partners)

1.2. Categories of Producers

In general, all sub-systems and components in the Detector System will be obtained from one of three possible sources: vendor contract, institutional partner, or in-house construction. Each of these approaches is distinct and offers unique challenges for communication and coordination. This makes the need for an effective quality control plan even more important. This document will emphasize the distinctions between each of these sources, and how will be addressed vis-à-vis quality control.

Vendor Contract

Components obtained via vendor contract are fabricated by an off-site vendor using plans and specifications which are included in the Statement of Work and have been verified to satisfy all pertinent project requirements. The vendor may be required to conduct in-process inspections and tests to assure that the component, production processes, and constituent materials meet specified standards, with documentation provided as specified in the Statement of Work. The completed product will be subject to inspection or test upon delivery to ensure that it meets project requirements.

Institutional Partners

Institutional partners differ from vendor contracts in that the institutional partner is often a stakeholder in the project and brings special expertise regarding how the system may be implemented. They may provide labor on component tests and/or assembly, they may provide paid services mixed with in-kind contributions of materials, facilities, and components, or at the extreme they may provide a full in-kind sub-detector. Institutional partners often coordinate through the L2 and L3 managers to make adaptations (within the scope of the requirements) that will improve the performance or versatility of their systems, or to incorporate new or emerging technologies.

Notably, this level of flexibility demands rigor in assuring system quality. Minimal critical specifications must be established, communicated, and verified. Final assembled detector performance often cannot be inspected without in-beam tests, but are contingent on the quality tests of various components. The impacts of any potential design modification must be evaluated against neighboring sub-systems, the detector system, and the EIC installation as a whole. Further, any adaptations made during the acquisition process must be reintegrated into the quality control plan.

Institutional partners remain subject to in-process tests and inspections to ensure quality and progress. The completed product is, as applicable, subject to inspection and test upon delivery. In some case, this may be a visual and verification of component specifications only, as assembled detector product performance requires in-beam tests.

In-House Construction

In house construction occurs when materials acquired by the project staff are used to fabricate, manufacture and assemble components and systems locally. Quality control in this case is multifaceted and applies across internal and external boundaries. To ensure accountability, quality control documentation must confirm the quality and compliance of materials provided by vendors independently from the work that is performed by staff members. Likewise, the quality of work that crosses institutional or organizational boundaries must be confirmed at every transition point to detect and isolate variances before they are propagated to other locations. Corrective action policies should be established to ensure that new issues can be addressed and brought into compliance as quickly as possible.

The likelihood of design adaptation is even higher with in-house construction, therefore all of the precautions that were identified for institutional partners must also be applied here. Further, in-house construction should also be subject to rigorous in-process tests and inspections to ensure quality, and the completed product is subject to inspection and test upon completion.

2. SCOPE OF QUALITY CONTROL PLAN

This Product Quality Control Plan address WBS items 6.10.XXX, 6.10.XXY, and 6.10.XXZ. This section will identify each component or assembly within a WBS that is subject to quality control. Further, it will identify the category of producers (as described above), which references the approach for quality assurance that will be used for that product.

2.1. WBS 6.10.03.01: Silicon Vertex Tracking (SVT) Detectors

The inner tracking system consists of a Silicon Vertex Tracker (SVT) based on thinned Monolithic Active Pixel Sensors (MAPS). The MAPS sensors used are developed in a 65 nm CMOS imaging process based-off the ALICE ITS3 development. MAPS/ITS3 silicon sensors. The SVT inner barrel layers directly use the ALICE ITS3 sensor, called MOSAIX. The SVT outer barrel and endcap disks use a modified MOSAIX sensor referred to as the EIC Large Area Sensor (EIC-LAS). Powering and communication will be provided by an Ancillary ASIC. The layers 0 – 1 of the inner barrel are constructed, assembled, and tested at INFN. Layer 2 is constructed, assembled, and tested at MIT (tentative). Completed layers (0 – 2) are shipped as half barrels to BNL. For the outer barrel, staves are built and tested at Oxford and then assembled into layers 3 – 4 at BNL. Staves for the disks are foreseen to be assembled and tested at LBNL, with also half disks assembled at LBNL, with completed half disks (20 total) to be delivered to BNL. Each of the institutional partners will perform QA on components at various assembly sites, and there is further QA on some components and full-assembled systems at BNL.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

<u>The following components are subject to quality control</u>

- Sensors: wafer probing of sensors (wafer-scale and EIC-LAS) prior to thinning and dicing,
- Ancillary ASICs: wafer probing prior to thinning (if any) and dicing,
- Flexible Printed Circuits (FPCs): electrical tests for the inner barrel, outer barrel, and disks.
- Assembled inner-barrel (half-)layers and shells (at a minimum electrical functionality) at assembly sites.
- Outer barrel modules (assemblies each consisting of two EIC-LAS, two ancillary ASICs, a bridge FPC).
- Outer barrel staves (electrical functionality, possibly mechanical and thermal) at assembly sites.
- Disk modules (assemblies each consisting of an EIC-LAS, an ancillary ASIC, and a bridge FPC),
- Half-disks (electrical functionality, possibly mechanical and thermal) at assembly sites.
- Readout boards - interface boards, control boards, power boards, (fiber) aggregator boards - following assembly and prior to shipping to BNL.
- Support cylinder and cones following production at production sites,
- Reception tests of IB, OB staves, half disks at BNL prior to installation (electrical).
- Global integration tests.

2.2. WBS 6.10.03.02: Micro-Pattern Gaseous Detector (MPGD) Trackers

The barrel outer MPGD trackers is based on GEM + uRWELL technology and will be assembled in Jefferson Lab , Florida Institute of Technology and University of Virginia. The inner barrel MPGD tracker is based on micromegas technology and will be produced and assembled in CEA-Saclay with significant in-kind contribution. The electron and hadron end cap MPGD trackers are based on GEM + uRWELL technology and will be assembled in INFN Roma Tor Vergata and Temple University with substantial in-kind contribution from INFN Roma Tor Vergata to procure GEMs and uRWELL PCBs. The assembled MPGD trackers will then be shipped from various assembly sites or institutional partners to BNL for final integration in ePIC. Each of the institutional partners will perform QA on each component of MPGD modules and only those will be selected for final assembly which satisfies the selection criteria.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

<u>The following components are subject to quality control</u>

- GEM foils
- GEM frames
- Printed Circuit Boards (for uRWELL or resistive layer of micromegas)
- Micromegas
- Drift cathode
- Drift cathode frames
- Voltage dividers
- Protection resistors on GEM foil sectors and uRWELL sectors.

2.3. WBS 6.10.04.01: High Performance Direct Internally Reflecting Cherenkov (hpDIRC) Detector

(HRPPD photo sensor: synergy with pfRICH)

The high-performance Direct Internally Reflecting Cherenkov detector is based on very high optical and mechanical quality quartz radiator bars. The default plan is to reuse the radiator bars that originate from the BaBar DIRC that have been transported from SLAC to Jefferson Lab. The backup solution would be to procure new radiation bars, carried in the risk registry. The assembly of the hpDIRC detector is foreseen to be at Jefferson Lab. A Cosmic Ray Telescope (CRT) has been constructed at Stony Brook University that can be used for complete quality test with cosmic rays of the assembled new DIRC bar boxes and was part of the R&D program. The default plan is to move this CRT to Jefferson Lab, do complete module QA there and then transport to BNL as full-assembled bar box modules, emulating the earlier successful transport of this fragile equipment.

<u>The following components are subject to quality control:</u>

- Radiator Bars (optical quality) refurbished from the BaBar DIRC

- Light guides (optical quality) to be purchased
- Focusing lenses systems (optical quality) 3 pieces for each bar
- Quartz coupling plate for each Bar Box
- Quartz expansion prism (optical quality) to be purchased
- Mirrors at for the far end of each long quartz bar (reflectivity)
- Photosensors, either HRPPDs in synergy with pfRICH or MCP-PMTs

2.4. WBS 6.10.04.02: Dual Ring Imaging Cherenkov (dRICH) Detector

(Aerogel radiator: synergy with pfRICH)

The Dual Ring Imaging Cherenkov detector will have significant in-kind contribution from INFN and hence assembly of various components of dRICH will take place in various Institutions of INFN. The assembled components of dRICH will be shipped to BNL where the final assembly of dRICH will take place. Only those components which satisfies the acceptance criteria based on specifications will be shipped to BNL.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- SiPM sensors
- Cooling system
- Aerogel radiator
- Gas radiator (Hexafluoroethane)
- Gas circulation and purification system
- Laser system for timing calibration of SiPM sensors
- dRICH vessel
- Mirrors

2.5. WBS 6.10.04.03: Proximity Focusing Ring Imaging Cherenkov (pfRICH)

(Aerogel radiator: synergy with dRICH, HRPPD photo sensor : synergy with hpDIRC)

The proximity-focusing Ring Imaging Cherenkov detector will be assembled at Brookhaven using components that are provided by institutional partners. The acceptance criteria for each of these components will be provided by the specifications. Some of these components may be produced by the vendor. Some components may be evaluated using in-kind institutional labor, while other components may be provided by an in-kind agreement.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Aerogel
- Mirrors
- Photosensors (HRPPDs)
- Vessel
- Laser Monitoring System

2.6. WBS 6.10.04.04: Time of Flight Detectors (TOF)

(AC-LGAD pixel: synergy with the Roman Pots/Off-Momentum Detectors, the B0 tracker, and the Luminosity Pair spectrometer)

The Barrel and Forward ToF detectors will be integrated to the support structure at BNL by using components provided by institutional partners. The staves, cooling system, service hybrids will be assembled and tested in partnering Institutions and will be accepted for final integration at BNL after satisfying performance criteria based on specifications.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Sensors (AC-LGAD)
- Asics (EICROC, FCFD)
- Cooling system
- Readout Board and Power Board (Service Hybrid)
- Flexible Printed Circuit Board
- Staves (integrated sensors and asics)
- Alignment system

2.7. WBS 6.10.05.01: Backward Electromagnetic Calorimeter

Backward EM Calorimeter plays a key role in scattered electron measurements with high requirements on energy resolution and capability for electron/pion separation. It will be built of $PbWO_4$ crystals with SiPM readout. Crystals and SiPMs will be delivered and QA tested in collaborating institutions and shipped to BNL for final assembly

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- PbWO4 crystals
- SiPMs and SiPM boards

2.8. WBS 6.10.05.02: Barrel Electromagnetic Calorimeter

Barrel EM Calorimeter needs to provide good energy resolution for photons and electrons in the required momentum range. It has to provide high rejection power for charged pions in electron identification, and to discriminate between a single photon and two photons from pi0 decay. The calorimeter will combine two technologies, lead-scintillating fiber (Pb/ScFi) sampling calorimeter with SiPMs readout, and silicon tracker comprising AstroPix, a monolithic active pixel sensor (MAPS) based on an HV-CMOS technology, which is interleaved with the Pb/ScFi layers to provide precise 3D imaging of calorimeter shower development. Pb/SciFi layers and AstroPix planes will be fabricated and QA tested in collaborating institutions and shipped to BNL for final assembly.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Scintillating fibers
- Pb/SciFi sectors
- Light Guides
- SiPMs and SiPM boards
- AstroPix Sensors/Modules/Staves/Trayes
- End-of-Tray readout cards

2.9. WBS 6.10.05.03: Forward Electromagnetic Calorimeter

Forward EM Calorimeter needs to provide photon, electron and pi0 measurements with good energy resolution in the required momentum range. Along with forward HCal, it shall provide high precision jet measurements. A sampling W/SciFi calorimeter with SiPM readout will be built in this region. W/SciFi blocks will be produced in collaborating institutions and shipped to BNL for final assembly.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Scintillating fibers
- W powder
- W/SciFi blocks and modules
- Light Guides
- SiPMs and SiPM boards

2.10. WBS 6.10.06: Hadronic Calorimeters

The Hadronic Calorimeter systems include three separate detectors in the backward (NHCAL), barrel (BHCAL), and forward (LFHCAL with insert) regions. The technology choice is based on steel-scintillator layers with SiPMs and H2GCROC readout for all systems. The BHCAL will be refurbished from the SPHENIX outer HCAL with modified electronics readout and SiPMs. Refurbishment will take place at BNL. The LFHCAL will have longitudinally segmented readout of 60 layers, grouped into six segments. The steel in the LFHCAL modules serves as flux return of the magnetic field of the detector solenoid. The modules will be produced by a vendor. The full detector modules will be assembled at ORNL; the readout electronics are being designed by ORNL and Debrecen University. The NHCAL design is similar to the LFHCAL with reduced nuclear interaction length. Modules will be assembled at Ohio State University.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

<u>The following components are subject to quality control:</u>

- Silicon photomultipliers
- Steel absorber modules for LFHCAL
- Absorber steel for NHCAL
- Injection molded scintillator tiles
- H2GCROC, summing boards, and long transfer boards

2.11. WBS 6.10.07: Solenoid Magnet

The detector solenoid has 3 main components:

a. magnet system (including coils and cryostat),
b. magnet power supply, and
c. conductor for the magnet

The conductor is once procured foreseen to be government-furnished material for the magnet system construction. The conductor will this be embedded into the magnet system that will be shipped to BNL for acceptance testing. The magnet power supply is a separate procurement.

<u>The following components are subject to quality control:</u>

- Magnet system (including coils and cryostat)
- Coils inner and diameter diameters and lengths

- Dimensions of the thermal shields and vacuum vessel
- Axial and Radial tie rods
- Lifting arrangements
- Fiducials for the alignment
- Pressure system compliance for the vacuum vessel
- Magnet power supply
- Overall operation of the power supply for electrical safety
- Dump resistor
- Quench detectors
- Conductor for the magnet
- Diameter of the strands
- Size of the cable
- Size of the soldered conductor

2.12. WBS 6.10.08: Electronics

The electronics readout chain includes various distinct components which will be subject to QA and QC during multiple fabrication steps.

The following components are subject to quality control:

- ASICs (millions of channels)
- Wafer Tests – performed at foundry for conformance to process parameters.
- Die - by sample, performed by the ASIC developers to assess conformance to design.
- Packaged devices – 100%, performed by developers and collaboration groups. Includes bump bonded and BGA devices.
- COTs (thousands)
- ADCs, DC/DC converters & power devices, optical transceivers – sample tested to verify conformance to production specifications.
- PCBs (thousands)
- Fab & assembly
- Bare board and post-assembly – by sub-contractors
- Flying probe, bed-of-nails, net tests, etc.
- Assembled PCBs
- Functional tests performed by collaboration groups, post assembly.
- Limited system integrated tests – full functional tests.
- Pre-installation full system integrated tests.

2.13. WBS 6.10.09: DAQ / Computing

There are two significant electronics projects, the FELIX Boards and the GTU within the WBS scope. There are also associated fiber runs, as well as a farm of approximately 200 COTS computers, and COTS network infrastructure.

The Felix Boards will be fabricated and assembled by external companies. A test protocol will be created and executed at BNL. The GTU will likely be developed, procured and tested at JLAB.

The following components will be subject to quality control:

- Felix Boards (140 boards)
- GTU (1-2 mother boards, 10-20 daughter boards)
- Fiber Runs

2.14. WBS 6.10.10: Infrastructure, Integration and Installation

The various components for III will either be assembled at Brookhaven using components that are provided by various vendors/international partners, or they will be assembled at the vendor's/international partner's facilities. The acceptance criteria for each of these components will be provided by the specifications. Some components may be evaluated using in-kind institutional labor, while other components may be provided by an in-kind agreement.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the component requirements will be fulfilled. Final performance will be determined by a combination of dimensional inspections and production testing of the components and assemblies, as part of ePIC and its facilities.

The following components are subject to quality control:

- Endcap Flux Return Steel for Hadron and Lepton Endcaps
- EPIC Detector Cradle
- Barrel HCAL Support Structure
- Magnet Support Structure
- All Inner Detector Support Structures (Barrel EMCAL, MPGDs DIRC, dRICH, pfRICH, EEEMCAL and All Si Detectors)
- Moving and Lifting Mechanisms for Endcaps and Barrel.
- All Installation Fixtures/Tooling
- Cooling Systems
- Gas Systems
- Platform Modifications
- Floor Modifications

2.15. WBS 6.10.11.01: Roman Pots and Off-Momentum detectors (RP/OMD)

(AC-LGAD: has synergy with the Forward TOF system, B0 tracking system, luminosity detector)

The Roman-Pots and Off-Momentum detectors will be produced and assembled at BNL. AC-LGAD sensors will be produced by Instrumentation division. The ASIC (EICROC) needed for the full stave production will be produced by international partners (though WBS 6.10....Fernando). Full stave will be assembled and integrated by BNL Instrumentation division. Cooling system will be designed and produced by international partners (IJCLab). Vacuum system will be designed, assembled and tested by BNL (in partnership with international partners (Brazil) and accelerator/vacuum team WBS ??) Staves will be mechanically integrated with cooling and vacuum systems by BNL and partnering Institutions. The acceptance criteria for this system will be provided by the specifications.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Sensors (AC-LGAD)
- ASICs (EICROC)
- Staves integration
- Vacuum system and integration
- Cooling system and integration
- Mechanical integration/Moving stages

2.16. WBS 6.10.11.02: B-Zero Detectors (B0)

(AC-LGAD: synergy with synergy with Forward TOF system, Roman Pots & Off-Momentum Detectors, luminosity detector; EMCAL: synergy with backward EM Calorimeter and the Zero-Degree Calorimeter)

The AC-LGAD sensors for B0 detector will be produced by the Instrumentation division at BNL. The ASIC (EICROC) needed for the full stave production will be produced by international partners (through WBS 6.10.08). Full staves will be assembled, integrated and tested by the Instrumentation division at BNL. The acceptance criteria for this system will be provided by the specifications.

The lead-tungstate PbWO4 crystals for the B0 Electromagnetic Calorimeter (B0-EMCAL), as well as their readout photosensors (SiPMs) will be produced, assembled and tested by international partners (Israel). The acceptance criteria for this system will be provided by the specifications. Some of these components may be produced by the vendor. Some components may be evaluated using in-kind institutional labor, while other components may be provided by an in-kind agreement.

Mechanical integration of tracking layers and calorimeter with cooling, beam-pipe and B0-magnet system will be done at BNL together with partnering Institutions.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Sensors (AC-LGAD)
- ASICs (EICROC)
- Stave integration
- PbWO4 crystals
- Photosensors (SiPMs)
- Mechanical integration

- Cooling system

2.17. WBS 6.10.11.03: Zero-Degree Calorimeter (ZDC)

(EMCAL: synergy with backward EM calorimeter, B0; HCAL: synergy with forward insert of the Forward Hadron Calorimeter)

The ZDC Electromagnetic Calorimeter (ZDC-EMCAL) crystals will be produced and tested by international partners. The acceptance criteria for this system will be provided by the specifications. Some of these components may be produced by the vendor. Some components may be evaluated using in-kind institutional labor, while other components may be provided by an in-kind agreement.

The ZDC Hadronic Calorimeter (ZDC-HCAL) section will be produced, assembled and tested by institutional partners. The acceptance criteria for this system will be provided by the specifications. Some of these components may be produced by the vendor. Some components may be evaluated using in-kind institutional labor. Some components will be re-used (Fe-blocks).

Mechanical support structure will be produced and assembled by JLAB/BNL.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Crystals
- Photosensors (SiPMs)
- Cooling system for EMCAL
- HCAL SiPM-onTile readout boards
- HCAL Photosensors (SiPMs)
- Mechanical support structure

2.18. WBS 6.10.11.04: Low-Q2 tagger (Low-Q2)

(EMCAL: synergy with Luminosity Detector and the Forward EM calorimeter)

Timepix tracker will be fully assembled and tested by international partners (Glasgow, UK). The acceptance criteria for this system will be provided by the specifications. Some of these components may be produced by the vendor. Some components may be evaluated using in-kind institutional labor, while other components may be provided by an in-kind agreement.

The Low-Q2 calorimeter will be fully assembled and tested by international partners (York, UK). The acceptance criteria for this system will be provided by the specifications. Some of these components may be produced by the vendor. Some components may be evaluated using in-kind institutional labor.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

<u>The following components are subject to quality control:</u>

- Sensors and ASICs (Timepix) modules
- Timepix Readout boards
- Cooling system
- Moving stages
- Calorimeter modules
- Photosensors (SiPMs)

2.19. WBS 6.10.14.01: Electron Polarimetry

The Electron Polarimetry system consists of polarimetry systems that exist in the Electron Storage Ring (ESR) and in the Rapid Cycling Synchrotron (RCS).

Polarimetry in Electron Storage Ring (WBS 6.10.14.01.01)

The laser system for the ESR Compton is under development at Jefferson Lab and will be fully tested there.

Diamond strip detectors for electron and photon detection will be assembled and tested at Jefferson Lab.

The photon calorimeter will be tested at Jefferson Lab – beam tests are possible depending on the beam schedule.

Polarimetry in the Rapid Cycling Synchrotron (WBS 6.10.14.01.02)

The (commercial) laser system for the RCS Compton will be tested at Jefferson Lab

Diamond strip detectors and associated electronics for photon detection will be assembled and tested at Jefferson Lab.

The photon calorimeter will be tested at Jefferson Lab – beam tests are possible depending on the beam schedule.

The L4 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the polarimeter requirements will be fulfilled. Final performance will be determined by a combination of laser diagnostics, cosmic tests at Jefferson Lab, possible beam tests at Jefferson Lab, and cosmic tests after installation at EIC.

<u>The following components are subject to quality control:</u>

- ESR Compton polarimeter system
- RCS Compton polarimeter laser
- Diamond strip detector boards for ESR and RCS Compton polarimeters
- Photon calorimeters for the ESR and RCS Compton polarimeters

2.20. WBS 6.10.14.02: Hadron Polarimetry

The Hadron Polarimetry system consists of the Hadron Polarimetry HJET system and the Hadron Polarimetry Fiber Targets.

Hadron Polarimetry HJET (WBS 6.10.14.02.01)

The HJET will undergo a number of changes with respect to the magnetic guiding field. The depolarizing resonances at the EIC induced by the beam will be much stronger compared to the ones present at RHIC due to the much higher bunch repetition frequency. At the EIC, a stronger holding field of about 350 mT compared to the RHIC magnetic field of 120 mT will reduce the risk as the remaining depolarizing resonances will be sufficiently weak to facilitate proper operation of the HJET with high target polarization to provide the absolute determination of the proton beam polarization. These modifications will be implemented ahead of time and tests of the full HJET with polarimeter and holding field will be conducted as a means to ensure the quality of the modifications. The detector systems that shall be used to detect elastically scattered recoil protons will be tested ahead of time using a similar HJET which will be installed in the AGS, whereby quality control of the detector system and electronics readout will be ensured.

The following components are subject to quality control:

- HJET plus Breit-Rabi polarimeter with modified holding field
- Recoil detector system and electronics readout

Hadron Polarimetry Fiber Targets (WBS 6.10.14.02.02)

The operation of the C fiber targets at the EIC have been shown to be feasible as the beam size at the future location in IP4 has been substantially increased compared to the present location in IP12. The simulations predict that the heating of the Carbon targets is tolerable, and thus the same target technology as at RHIC can be applied for relative beam polarimetry and polarization profile measurements at the EIC. The present quality assurance protocols for the carbon targets at RHIC have been ironed out over the course of the past 20 years, and these protocols will be applied to ensure the same for the EIC carbon polarimeters. The detector system and electronics readout of the pC polarimeter will employ the same components as the HJET polarimeter, and quality assurance will be provided through early testing and assembly of components and electronics readout using the AGS polarimeter setups.

The following components are subject to quality control:

- C target manufacturing procedure
- Recoil detector system and electronics readout

2.21. WBS 6.10.14.03: Luminosity system

(AC-LGAD tracker: synergy with Forward TOF system, Roman Pots & Off-Momentum Detectors, B0-tracker;   EMCAL: synergy with Low-Q2 detector and Forward EM Calorimeter)

The AC-LGAD sensors for the Luminosity Pair Spectrometer detector will be produced by the Instrumentation division at BNL. The ASIC (EICROC) needed for the full stave production will be produced by international partners (though WBS 6.10.08 electronics). Full staves will be assembled, integrated and tested by the Instrumentation division at BNL. The acceptance criteria for this system will be provided by the specifications.

Luminosity calorimeters will be fully assembled and tested by international partners (York, UK) The acceptance criteria for this system will be provided by the specifications. Some of these components may be produced by the vendor. Some components may be evaluated using in-kind institutional labor, while other components may be provided by an in-kind agreement.

Magnets

Details of included magnets.

Vacuum System with Conversion Foil

Details of vacuum system.

Collimators

Details of collimators.

The L3 Control Account Manager will be the point of contact for information about how these processes will be conducted once the project is baselined. Confirmation of the quality of the various components assures that, when assembled, the sub-detector requirements will be fulfilled. Final performance will be determined by a combination of cosmic run tests and beam tests of the fully assembled detector, as part of the ePIC detector.

The following components are subject to quality control:

- Sensors AC-LGADs
- ASICs (EICROC)
- Stave integration
- Cooling system
- Moving stages
- Calorimeter modules
- Photosensors (SiPMs)
- Magnets
- Vacuum system with conversion foil
- Collimators

3. REQUIREMENTS TRACEABILITY

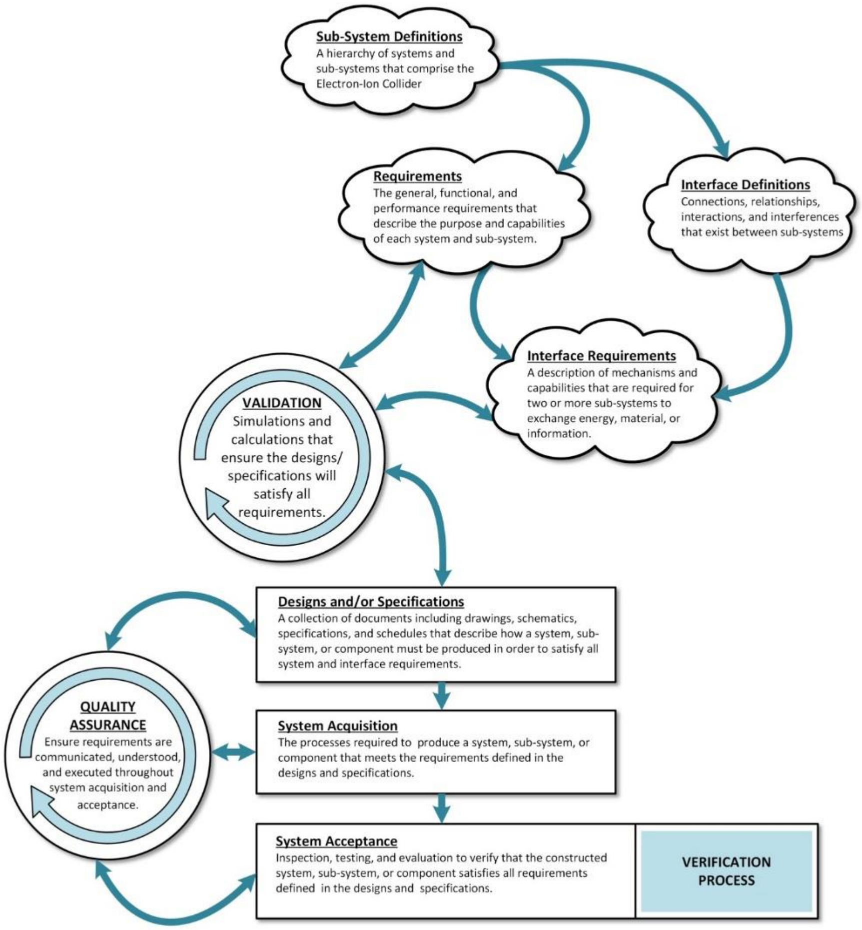


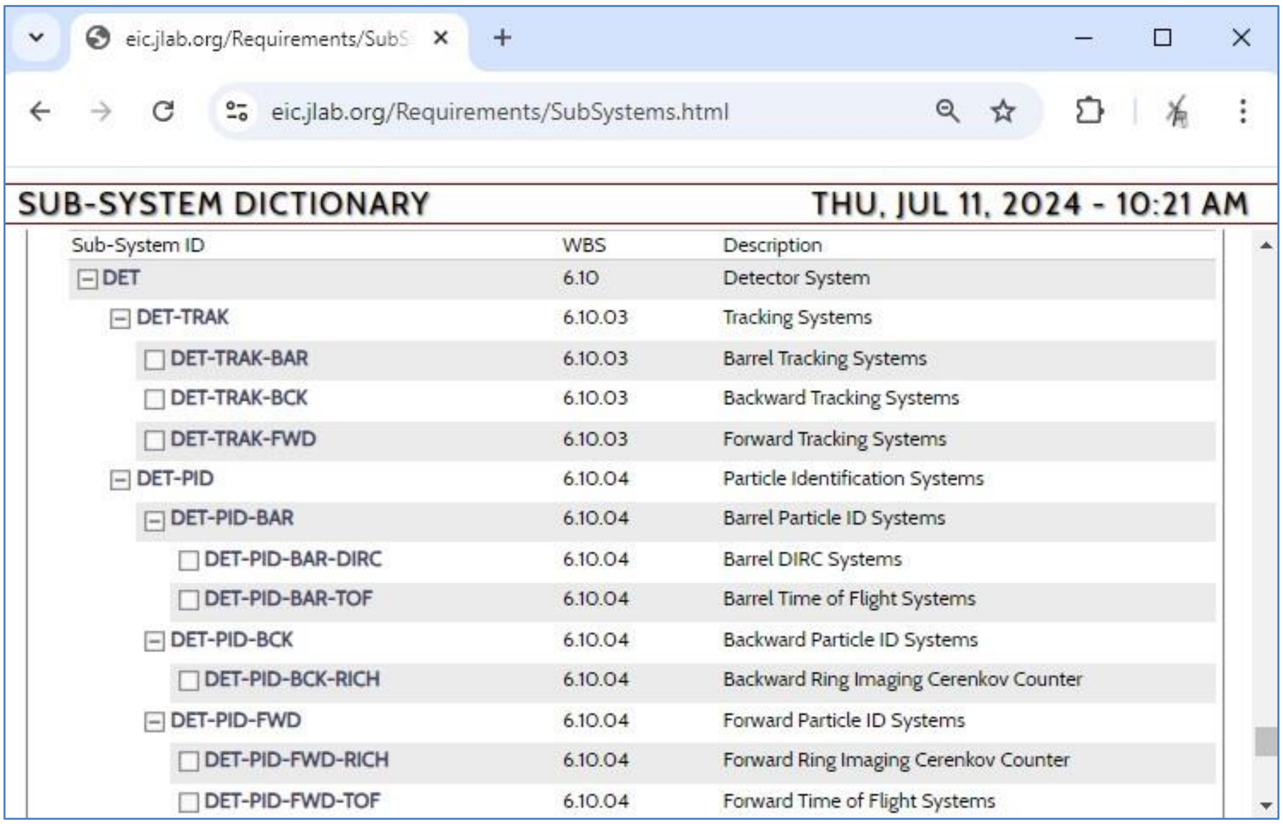
Figure 1. Flow of Requirements Through the System Acquisition Process

Requirement traceability in the EIC project is accomplished by using the hierarchy of sub-systems, requirements and interface definitions that have been documented on the EIC Systems Engineering Portal (https://eic.jlab.org). These requirements are maintained within the Visure database, whose data is regularly downloaded and processed to update the web portal. After the requirements are validated using simulations and calculations, they are used to develop designs and/or specifications that provide precise details on how the sub-system or component should be produced. These designs/specifications are used to produce the sub-system, and the quality assurance process ensures that the process remains in compliance with the requirements throughout the system acquisition and acceptance process.

The following sections describe the features and characteristics of each element in Figure 1.

3.1. Sub-System Identifiers

For the EIC projects, system requirements are associated with individual sub-systems. A sub-system is an operable element within the larger system that is tagged with a unique sub-system identifier using the taxonomy described in the Requirements Management Plan. The sub-system identifiers create a hierarchy that is based on the physical manifestation of the system, rather than the work breakdown structure (WBS). Each sub-system identifier is linked to a WBS number to provide a relational link to the project. A complete dictionary of sub-system identifiers can be found at the EIC Systems Engineering Portal. Figure 2 shows an extract from the Sub-System Dictionary.



Sub-System ID	WBS	Description
DET	6.10	Detector System
DET-TRAK	6.10.03	Tracking Systems
DET-TRAK-BAR	6.10.03	Barrel Tracking Systems
DET-TRAK-BCK	6.10.03	Backward Tracking Systems
DET-TRAK-FWD	6.10.03	Forward Tracking Systems
DET-PID	6.10.04	Particle Identification Systems
DET-PID-BAR	6.10.04	Barrel Particle ID Systems
DET-PID-BAR-DIRC	6.10.04	Barrel DIRC Systems
DET-PID-BAR-TOF	6.10.04	Barrel Time of Flight Systems
DET-PID-BCK	6.10.04	Backward Particle ID Systems
DET-PID-BCK-RICH	6.10.04	Backward Ring Imaging Cerenkov Counter
DET-PID-FWD	6.10.04	Forward Particle ID Systems
DET-PID-FWD-RICH	6.10.04	Forward Ring Imaging Cerenkov Counter
DET-PID-FWD-TOF	6.10.04	Forward Time of Flight Systems

Figure 2. Excerpt from Sub-System Dictionary

The Sub-System Dictionary does not uniquely identify every individual component within the system. Rather, it is used to define a 'sensible' aggregation point within a system, below which all components are subject to the same general, functional and performance requirements.

3.2. System Requirements

System requirements are allocated at the sub-system identifier level, and have a unique identifier that associates them with a sub-system. Unless otherwise specified, all requirements that are defined for a parent sub-system are also applicable to, or constrain the design of, its children. For the EIC project, requirements are defined as general, function, or performance. These are defined as follows:

Requirement Types

- **General Requirements:** provide the high-level definition of what the sub-system is, what role it plays within the larger system, and the relationships that it has with internal and external entities.
- **Functional Requirements:** describe the specific functions that the sub-system must perform or support. In addition to the sub-system's functionality, functional requirements also define any external functionality that the sub-system relies on to accomplish its work.
- **Performance Requirements:** describe how well each of the functional requirements must be performed. These define the minimum satisfactory levels of performance for the sub-system to continue operations and accomplish its purpose, as well as the levels of performance that are required of the systems that are supporting it.

Hierarchy of Requirements

As with the sub-system dictionary, requirements form a hierarchical tree that relates them to one another. Each performance requirements must be linked to a functional requirement (or function) whose quality or performance it describes. Each functional requirement is linked to a general requirement that justifies why this function is necessary. This hierarchy provides an auditable structure that ensures that all requirements are fully justified.

3.3. Interface Definitions

Interface definitions are used to identify each of the connections, relationships, interactions, and interferences that exists between sub-systems. These relationships may exist between systems, sub-systems, infrastructure, or external entities. Interfaces are typically mechanisms for transferring energy, material, or information between entities, but may also describe physical boundaries that are established to prevent interferences or interactions. Like requirements, each interface is assigned a unique identifier using the taxonomies described in the Requirements Management Plan and the Interface Management Plan

3.4. Interface Requirements

Interface requirements expand on the description of each interface that is identified in the Interface Definitions document. These requirements detail the specific features and capabilities that an interface must have to satisfy the needs of all its supported systems and components. In order for an interface requirement to be validated, all sub-systems that utilize it must confirm that it satisfies their requirements and will be able to achieve its stated purpose.

3.5. Designs and/or Specifications

This category includes designs, technical specifications, tests procedures, inspection and acceptance criteria, and all other documentation that is used to produce sub-systems and components. The designs and specifications represented by these documents are directly associated with the requirements and interface definitions, and are validated through simulations and calculations. The quality assurance process ensures that these documents will provide sufficient information for a component or sub-system to be produced that will satisfy all requirements.

These documents will be made available via a non-volatile document index on the EIC Systems Engineering Portal. This index uses a unique identifier to reference each document, and provides a link to where the pertinent version of the document may be found. Note that this non-volatile index serves only as a central reference point for the information. In many cases these documents may not be stored locally, but may refer to a document in a repository at a partner institution. This is a critical feature, particularly when specifications are under development and are rapidly changing. As specifications and designs are finalized, the documents should be drawn into a central repository and the index updated to reflect the new location.

3.6. Acquisition and Acceptance

System acquisition represents all of the processes that are required to produce a system, sub-system, or component that meets the requirements as defined in the plans and specifications. The quality assurance process will define regular intervals for meetings, inspections, tests, and other activities that are deemed necessary to ensure that the product will satisfy all requirements.

The system acceptance process includes inspections, testing, and evaluation to verify that the deliverable satisfies all requirements, includes all documentation and supplemental material, and meets all specific metrics that were included in the quality assurance plan.

SPECIFIC QUALITY CONTROL MEASURES

4. IN-PROCESS INSPECTION AND TEST

In-process inspections and tests provide a mechanism for detecting non-conformances in materials, components, or assemblies during fabrication and assembly. This allows problems to be identified and corrected as early as possible, minimizing the impact of manufacturing deficiencies.

As part of the validation, verification and testing plan document, an in-process inspection and test plan will be developed for all applicable components and sub-systems that are being manufactured or assembled. This section is specific to items being produced in house, while the following section addresses items that are being produced by vendors or partner institutions.

The plan may be a single document, or may make use of existing travelers or other suitable planning and control documents. It shall address the Material Requirements Planning (MRP), and at a minimum include manufacturing, inspection, and test steps including identification of critical manufacturing operations and parts/subassemblies showing integrated flow into the end item(s).

Test plans, technical reports, test results, and other documentation resulting from these inspections and tests will be compiled into a report and provided to the project as part of the deliverable. This report will be reviewed, validated, and then placed in the central data repository. The document will be referenced through the document index on the EIC Systems Engineering portal.

5. OUTSOURCING: VENDOR/PARTNER/CONTRIBUTORS IN-PROCESS

In-process inspections and tests for outsourced components will be addressed differently for each category of providers. In all cases that tests and inspections are required, a test plan will be developed and approved by the project. As with in-house inspections and tests, the plan may be a single document, or may make use of existing travelers or other suitable planning and control documents.

For each category specified below, the types of inspections and required tests will be specified in one or more documents. These documents identify the schedule and frequency of such tests, how the results will be reported, and which material and documentation should be supplied to the project with the deliverable.

- Vendor Contract

  Inspections and tests will be identified in the **Statement of Work**.

- Industrial Partners

  Industrial partners have multiple mechanisms for providing services and materials and each of these is handled differently. The following documents dictate the inspections and tests that will be required for each mechanism.

  - In-kind Contribution: Inspections and tests are identified in the **Project Planning Document.**
  - Service Agreements: Inspections and tests are identified in the **Statement of Work.**
  - In-kind Labor: Inspections and tests are identified in the **Work Agreement.**

6. INCOMING INSPECTION AND ACCEPTANCE TESTS

Incoming inspections and acceptance tests are used to confirm that materials or products provided by a vendor or partner institution have been produced in accordance with the plans and specifications, and meet all system requirements. These plans should be developed in conjunction with the transportation and shipping plans to account for potential impacts of moving items between locations.

As part of the validation, verification and testing plan document, the incoming inspection and test plan will be developed for all applicable components and sub-systems that are being manufactured or assembled by a vendor or partner institution. Inspection and acceptance plans may be developed for each individual component, or a single test plan may be constructed that is applicable to multiple items.

For each category specified below, the types of inspections and required tests will be specified in one or more documents. These documents identify the schedule and frequency of such tests, how the results will be reported, and which material and documentation should be supplied to the project with the deliverable.

- Vendor Contract

  Inspections and tests will be identified in the **Statement of Work**.

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  - In-kind Contribution: Inspections and tests are identified in the **Project Planning Document**.
  - Service Agreements: Inspections and tests are identified in the **Statement of Work**.
  - In-kind Labor: Inspections and tests are identified in the **Work Agreement**.

Test plans, technical reports, test results, and other documentation resulting from these inspections and tests will be compiled into a report and will be provided to the project as part of the deliverable. This report will be reviewed, validated, and then placed in the central data repository. The report will be referenced through the document index on the EIC Systems Engineering portal.

7. TRAVELERS, PROCEDURES, AND CHECKLISTS

For every item that is manufactured, the manufacturer will be responsible for maintaining records (travelers) of all raw material that are used in the fabrication process, and document the processes and procedures that were used for production. The resultant documentation will be compiled into a report and will be provided to the project as part of the deliverable. This report will be reviewed, validated, and then placed in the central data repository. The document will be referenced through the document index on the EIC Systems Engineering portal.

8. VERIFICATION PLANS: METHODS AND ACTIVITIES

Verification plans are tightly coupled with all inspection and testing procedures. They are used to establish a comprehensive plan to communicate the nature and extent of testing that is necessary for a thorough evaluation of the system. These plans are used to coordinate the orderly scheduling of events by providing equipment specifications and organizational requirements, the test methodology to be employed, a list of the test materials to be delivered, and a schedule for user (tester) orientation and participation. Finally, it provides a written record of the required inputs, execution instructions, and expected results of the system test.

A validation, verification and testing plan document will be developed from the standard template that details the following information:

a. test evaluation criteria
b. user system acceptance criteria
c. the overall testing schedule (to include documentation review, test scripts, data preparation, test execution, output review, system certification, and system release)
d. security requirements
e. equipment, software, and personnel requirements
f. test characteristics (to include testing conditions, extent of testing, data recording and testing constraints)
g. test descriptions detailing each scheduled test

These tests may be specified as needed for material acquisitions, or for parts, components, or assemblies that are purchased, manufactured, or assembled. The following documents identify which verification methods and activities must be performed.

- In-House Construction

  Verifications methods and activities are specified in the **Work Planning Documents**.

- Vendor Contract

  Verifications methods and activities are specified in the **Statement of Work**.

- Industrial Partners

  Industrial partners have multiple mechanisms for providing services and materials and each of these is handled differently. The following documents dictate the verifications methods and activities that will be required for each type.

  - In-kind Contribution: Specified in the **Project Planning Document**.
  - Service Agreements: Specified in the **Statement of Work**.

- In-kind Labor: Specified in the **Work Agreement**.

The resultant documentation will be compiled into a report and will be provided to the project as part of the deliverable. This report will be reviewed, validated, and then placed in the central data repository. The document will be referenced through the document index on the EIC Systems Engineering portal.

9. DELIVERABLE DOCUMENTATION AND RECORDS

Documentation and records that must be provided to the project will be specified in the Statement of Work, Project Planning Document, work agreement, or work planning documents as discussed in the preceding sections. Additionally, all testing and inspection data that is collected as part of the validation, verification and testing plan will be provided to the project as part of the final report.

10. ASSOCIATED EQUIPMENT

Associated equipment describes tools, parts, materials, components, fixtures and assemblies that are independent of the final product. Any associated equipment that must be delivered to the project will be identified in the Statement of Work, Project Planning Document, work agreement, or work planning documents as discussed in the preceding sections. Conditions of acceptance of this material will be described in the validation, verification and testing plan.

11. CALIBRATION PLANS

Vendors, partners, and employees shall calibrate any measuring and test equipment used in production or testing against certified standards that are traceable to national standards such as the National Institute of Standards and Technology (NIST), or an international standard, or a physical constant. They shall notify the project of any condition found during the calibration, servicing or repair of measuring and test equipment that can affect the end item requirements.

For calibrations that are required by the statement of work, contract, or formal work agreement, a calibration plan will be developed. At a minimum, the calibration plan will provide the following information.

- Which equipment needs to be tested
- Inspection and measurement processes

  May include manufacturer and model of testing equipment, frequency of calibration, traceability standards, validation certificates, and details of actions to be taken in the event of unsatisfactory results.

- Calibration Frequency

  Typically depends on the equipment's purpose, manufacturer's specification, degree of usage, equipment type, or demand for stability/reliability.

- Responsibilities and Qualifications

  Used to ensure that the individuals performing the tests are trained and qualified to perform the work and to ensure that the test equipment is in proper condition.

- Custody of calibration tools

  Does the process require a chain of custody to ensure that equipment is secure and protected between calibrations and usage?

- Relevant standards

  What standards will be used to perform the calibration?

12. SERIALIZATION AND MATERIAL TRACEABILITY REQUIREMENTS

Parts and materials will be serialized as defined in the statement of work, contract, or formal work agreement. Note that in numerous detector components serialization is NOT possible, because it would degrade overall detector performance. The method of serialization will be agreed upon by the producer and the project prior to acceptance of the final design. Items that have been serialization will be identified and documented in the travelers associated with each shipment.

13. PLANNED PARTNER AND VENDOR COMMUNICATION & VISITS

Periodic program technical and progress telecommunications and/or meetings between the vendors/partners and project leaders will be conducted. Often these are specified in the statement of work, contract, or formal work agreement, if they are separate from the regular detector collaboration meetings *(current calendar can be viewed at* https://indico.bnl.gov/category/402/calendar *)*. Discussions will include the work progress, technical and contractual questions, presentations of analysis or testing results, troubleshooting, material status, tooling status, resources, and manufacturing issues.

14. CONTROL OF NONCONFORMANCES

Vendors, partners, and in-house providers are responsible to provide items which conform to the requirements of the contract or work agreement, regardless of any assessments, surveillances, inspections and/or tests that are conducted as part of the validation and verification process. Non-conformances, significant variations in quality, recalls, and alerts will be reported to the project.

15. PACKAGING/TRANSPORTATION/SHIPPING

In preparation for shipping, a packaging plan will be developed that will be reviewed and approved by the project prior to shipment. The packaging plan should address all phases of the shipping process, to include:

a. Packaging
b. Loading and material handling
c. Environmental requirements while being staged and shipped
d. Shock and vibration sensitivity and mitigation
e. Durability/lifetime/shelf life during and after shipping
f. Off-loading
g. Staging and storage requirements upon delivery

Preservation, packaging, and packing for shipment or mailing of all work deliverables shall be in accordance with standard commercial practice and adequate to insure acceptance by common carrier and safe transportation at the most economical rates.