HL-LHC CMS Detector Upgrade Project

Preliminary Hazard Analysis Report (pHAR)

Fermi National Accelerator Laboratory

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Fermi National Accelerator Laboratory

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Fermilab

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Change Log

Revision No.	Summary of Changes	Effective Date
v 1.0	Initial version	September 7, 2017
v1.1	Updated and reviewed content for CD-1	February 20, 2018
v1.2	Updated to include Timing Layer	April 13, 2018
v1.3	Cryo Safety Committee	April 13, 2018
v1.4	Generalize to a National Plan	June 20, 2018
v1.5	Edit to include ESH&Q Section comments	July 23, 2018
v1.6	Minor cosmetic edits to text; update of signatories	September 5, 2018
v1.7	Fixed dates, second update of signatories, fixed typos.	September 10, 2018
v1.8	Replaced ES&H Coordinator by ES&H Manager, fixed reference 2 and version number in header, fixed typos and made text clearer overall.	September 21, 2018
v1.9	Updated signatories page, added more MTD Institutions in Table 2, and implemented minor format changes.	November 11, 2018

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1.0 Executive Summary

The CMS High Luminosity Large Hadron Collider (HL-LHC) Detector Upgrade is an international project to upgade the CMS detector at CERN in Meyrin, Switzerland. The U.S. CMS HL-LHC Upgrade collaboration is committed to insuring the safety of its users, staff and the public while executing a successful completion of the mission objectives of the U.S. CMS HL-LHC Upgrade Project. To help fulfill these commitments, a Hazards Analysis has been conducted to anticipate and address the hazards that will be encountered during the project's construction, installation and operational phases.

All hazards identified are typical of those encountered with other high energy physics projects at accelerator facilities across the DOE complex. The design and operational criteria to mitigate these hazards, resulting from many years of operational experience and lessons learned, will be applied to the HL-LHC CMS Upgrade Project. There are no unmitigated risks that are deemed to be *Critical* but a number of potentially *High* risks could be present in this project in the absence of passive mitigation. When taking into account the planned passive mitigations there are no risks higher than *Moderate* and most are *Low* or *Minimal*. Risk levels as used in this document are defined in Fermilab Quality Assurance Manual (QAM) Chapter 12030[1]. Active mitigation measures will reduce the risks even further.

This document covers hazards during the design, prototyping, production, and testing at U.S. institutions. Once the detectors are shipped to CERN to be integrated with and installed in the CMS detector, the CERN safety practices and assessments will apply. ESH mitigation is considered during the design of the detectors. In addition, before construction begins, CERN/iCMS reviews all designs to ensure the final instrument complies with CERN safety standards and procedures.

2.0 Introduction

It is the policy of the U.S. CMS HL-LHC collaboration to set a culture and work environment that will protect the natural environment and all persons, be they collaborators at national laboratories, universities or commercial vendors, from accident or injury while they are engaged in efforts on this project. Nothing shall have a higher priority. We have adopted the Fermilab Environment, Safety and Health Manual (FESHM) to specify a set of physical and administrative requirements that define the boundary conditions for safe operation during a detector manufacturing project. FESHM 2060, '**Work Planning and Hazard Analysis'** calls for identification of hazards and for assessment and mitigation of risks at facilities such as the Fermilab Silicon Detector Facility (SiDet), where fabrication of some components will take place. Universities participating in detector construction will be expected to adhere to local ES&H plans, which will be verified in consultation with the U.S. CMS HL-LHC Upgrade Project ES&H Manager and the Fermilab ESH&Q Section. The goal is to demonstrate that there is reasonable assurance that operations can be conducted in a manner that will limit risks to the health and safety of project collaborators, subcontractors, and the public and will adequately protect the environment.

It is important to note that the Hazard Analysis required by the above chapter is not an evaluation of the actual risk from HL-LHC CMS Upgrade activities, but is an evaluation of the hazards which might be encountered in such a project, in the absence of the engineered mitigations. Only passive mitigations are to be taken into account in evaluating the different hazards identified; it is to be assumed that engineered mitigations such as alarms, detectors, interlocks, ventilation, and operational procedures are all inoperative or compromised.

In this report, sections 3.0 and 4.0 describe the hazard identification and assessment methodology used, and the results of applying the process to the project are detailed. Consequences were considered at both Fermilab and participating universities. While the upgrade will be guided by the ES&H procedures in place at Fermilab, the off-site construction and installation activities will be assessed according to the best practices and ES&H frameworks of the institutions involved. Prior to authorizing production to occur at university sites, sufficient ES&H documentation and procedures will be reviewed by the U.S. CMS HL-LHC Upgrade ES&H Manager, who will consult with Fermilab ES&H professionals to ensure the procedures are likely to mitigate hazards. Section 5.0 presents the conclusion that the HL-LHC CMS Detector Upgrade Project activities can be characterized as low hazard when passive mitigation procedures are implemented.

3.0 Methodology

The methodology used was selected to provide a uniform and thorough process for identifying and assessing the hazards present to personnel and the environment. The process consisted of the following three steps which are described in more detail further below:

1) Development of a list of potential significant hazards.
2) Assessment of the HL-LHC CMS Upgrade project plans for the presence of these potential hazards.
3) Assessment of the probability for a possible mishap or equipment failure and the severity of the consequences.

A detailed list of potential hazards that may be encountered by a detector upgrade project was developed by following the process outlined in FESHM 2060.[2] This chapter contains Fermilab's analyses of the hazards likely to be confronted during the execution of this upgrade project and relevant statutory requirements. In addition, typical mitigation efforts are detailed that should be followed in order to mitigate these hazards. A list of potentially significant hazards was then prepared from this master list for use in assessing the project. Hazards that are only of a magnitude and type routinely encountered and/or accepted by the general public were not included nor were hazards that are mitigated by code compliance (National Electrical Code, International Building Code, etc.) or by OSHA compliance. The resulting potential hazard list is included here as Attachment A. It primarily contains risks that result from the technical aspects of detector construction.

The major deliverables of the DOE U.S. CMS HL-LHC project are upgrades of the HL-LHC CMS Level 1 Trigger, the Outer Tracker, the Endcap Calorimeter, and the MIP Timing Layer. The scope of this hazard analysis encompasses electronics design and testing activities, the construction of Outer Tracker modules and mechanics, the construction of Endcap Calorimeter cassettes, the construction of MIP Timing Layer modules and electronics, and shipment to CERN. Both university and Fermilab hazards are considered. The scope does NOT include the detector integration tasks at CERN, the installation of any of the upgrades into the CMS detector, or their operation at CERN. Safety assessments for these phases will be performed in accordance with the procedures of CERN, which operates CMS.

4.0 Results and Assessments

The results of the second step in the Hazard Analysis methodology, hazard identification, are presented in Table 1 using a matrix of hazard type versus WBS activity. During the project, we can expect to encounter mechanical hazards, electrical hazards, fire hazards, oxygen deficiency and CO_2 toxicity hazards, cryogenic hazards, laser hazards, radiation hazards, flammable material hazards, toxic material hazards, and electrostatic discharge hazards. The next step in the analysis will be ranking these hazards according to the ranking process described in QAM 12030[1] assessing various risks related to environment or safety and health activities. Classification of the identified hazards was and will continue to be documented using a Hazard Analysis worksheet. Each identified hazard was characterized according to hazard type, mishap consequences, and initiating event. Assignment of a risk ranking corresponding to the QAM Chapter 12030[1] will be done in consultation with the Fermilab ESH&Q Section staff. These evaluations will be conveyed to university safety personnel for remote assembly sites. Also included are descriptions of the installed hazard mitigation measures at Fermilab assembly locations, both passive and active (engineered). These actions will be conveyed to university assembly locations to guide them in creating comparable safety measures. In the risk ranking procedure, credit will only be taken in the assessment for all passive mitigation features, but the active mitigations planned are included for completeness. The set of Hazard Analysis worksheets is included as Attachment A.

WBS Number	WBS Description	Mechanical	Leak & Spill	Electrical Hazards	Fire Hazards	Oxygen deficiency and CO_2 toxicity	Cryogenic Hazards	Laser Hazards	Radiation Hazards	Flammable	Toxic Material	Environmental	ESD Hazards
402.01	Management Management support (financial & budget), travel, workshops, integration planning												
402.02.03	Outer Tracker: Sensors			×	×				×				×
402.02.04	Outer Tracker: Electronics			×	×				×	×			×
402.02.05	Outer Tracker: Modules	×	×	×	×				×				×
402.02.06	Outer Tracker: Mechanics	×		×	×	×	×			×	×	×	
402.02.07	Outer Tracker: Integration	×		×	×	×	×						×
402.04.03	Endcap Calorimeter: Sensors	×	×	×	×				×	×			×
402.04.04	Endcap Calorimeter: Modules	×	×	×	×				×	×			×
402.04.05	Endcap Calorimeter: Cassettes	×		×	×	×	×		×	×	×		×
402.04.06	Endcap Calorimeter: Backing Hadronic				×			×	×	×		×	
402.04.07	Endcap Calorimeter: Electronics and Services			×	×				×	×			×
402.06.03	Trigger / DAQ: Cal Trigger			×	×					×			×
402.06.05	Trigger / DAQ: Correlator Trigger			×	×					×			×
402.06.06	Trigger / DAQ: DAQ												
402.08.03	Timing Layer: Barrel Timing Layer	×		×	×	×	×		×	×			×
402.08.04	Timing Layer: Endcap Timing Layer	×		×	×	×	×		×	×			×

Table 1: Hazard identification for both university and national laboratory located activities.

4.1 Manufacturing and Assembly

Safety and health hazards that will be encountered in the U.S. CMS HL-LHC Upgrade Project are common hazards for detector upgrade construction. A hazard analysis will be conducted as part of the job planning process to evaluate the hazards to personnel during the manufacturing, assembly and testing of these components and to identify the means to mitigate the hazards.

4.1.1 Mechanical Hazards

Construction of the Outer Tracker detector will involve transporting, lifting, moving, positioning, and assembly of only moderately large (~2m length), lightweight but expensive components.

Construction of the Endcap Calorimeter cassettes will involve transporting, lifting, moving, positioning, and assembly of components approximately 2m x 1m. They weigh between 100-150 kg, therefore requiring special equipment to handle, and made of expensive components.

Construction of the Timing Layers involves delicate layers of maximum 15kg weight.

4.1.2 Electrical Hazards

The readout and/or frontend electronic systems being manufactured for the project and the hazards associated with them are very similar to those encountered frequently at Fermilab for the accelerator and experiments. No high voltages are required in the construction, operation, or testing of the systems, except for the low current silicon sensor bias voltage that is applied during sensor tests. The hazards associated with the sensor bias voltages will be mitigated by employing shielding and test enclosures that prevent physical contact with the high voltage.

4.1.3 Radiation Hazards

Electronics and detector testing may involve the use of the particle test beam facilities at Fermilab or other facilities. Radioactive sources or X-ray equipment may also be used in the testing of the sensors. Radiation hazards will be mitigated by insuring that all personnel working at test beams or with radioactive sources have received Radiation Worker and source training as appropriate.

At Fermilab, the test beam itself is covered by its own Safety Assessment Document (SAD).[3] At other test beam or irradiation facilities, workers will comply with local safety procedures.

4.1.4 Industrial Hygiene

Industrial Hygiene issues to be addressed during the construction and testing of components include handling of cryogenic liquids, handling of toxic or allergenic materials during construction, and working with CO_2 systems.

Detector electronics may contain small amounts of lead in the solder used for assembly. Local ES&H personnel will evaluate these incidental exposures and advise personnel on any Personal Protective Equipment (PPE), procedures, or training that may be required.

The control of hazards in these categories is addressed through the application of the Occupational Safety and Health Act and other relevant standards, such as American National Standards Institute (ANSI) and American Conference of Governmental Industrial Hygienists (ACGIH), as well as the FESHM when work is conducted at Fermilab. Work performed on the U.S. CMS HL-LHC Upgrade project will be conducted in conformance with these standards. Hazards in the Industrial Safety category can be mitigated by insuring that all personnel working on detector construction have received the applicable safety training for their assignments.

4.1.5 Cryogenics, Oxygen Deficiency and CO_2 Toxicity Hazards

The project will use liquid CO_2 to cool the sensors. At Fermilab, a CO_2 system for cooling small test assemblies (Outer Tracker) will likely reuse an existing coldbox. A larger coldbox will be needed to test the Endcap Calorimeter Cassettes. A coldbox will be needed to test the Timing Layer. An operational readiness review of any cryogenic system operated at Fermilab will be conducted by the PPD Division Safety Officer (DSO), in conjuction with the designated Cryogenic Safety Subcommittee review panel, in accordance with established ES&H procedures. The existing cryo box was already reviewed.[4] If cryogenic operations are necessary at university sites, the university ES&H personnel will be consulted to ensure proper safety operations and the safety plan will be reviewed by the U.S. CMS HL-LHC Upgrade Project ES&H Manager and/or independent ES&H subject matter experts.

4.1.6 Environmental Protection

There are no activities in the HL-LHC CMS Upgrade Project manufacturing and assembly which have a potential for significant environmental impact. The HL-LHC CMS Detector Upgrade Project has a reviewed Environmental Evaluation Notification Form in compliance with the National Environmental Protection Act (CMS-doc-13483).

4.1.7 Electrostatic Discharge (ESD) Damage

The Endcap Calorimeter, Outer Tracker and Timing Layer detectors contain a large number of silicon diode detectors that are susceptible to damage from electrostatic discharges. Other semiconductor components in other electronic assemblies might also be susceptible. This represents no hazard to personnel. This hazard has been addressed by providing adequate ESD protection measures according to industrial best practice and by instituting an ESD training course which all personnel involved in sensor handling are required to complete.

4.1.8 Waste Handling, Storage and Disposal

Radioactive and hazardous chemical wastes have the potential to be very dangerous. However, the U.S. CMS HL-LHC Upgrade Project will generate minimal amounts of either. No radioactive wastes will be generated by the construction. Small amounts of hazardous chemicals may be generated, and disposal will be handled according to the FESHM at Fermilab and by equivalent protocols at university sites. Disposal protocols at all sites will provide a comparable level of safety as those described in the FESHM, Chapter 8021. These protocols will be verified by the U.S. CMS HL-LHC Upgrade Project ES&H Manager and/or independent ES&H subject matter experts.

4.2 Identification of Assembly sites

The equipment for the U.S. CMS HL-LHC Upgrade will be designed, assembled and tested at a variety of universities and at Fermilab. This will necessitate that a safety plan be developed and rolled out to the entire project. The procedures to accomplish this are described in the U.S. CMS HL-LHC Upgrade Integrated Safety Management (ISM) plan[5]. However, the individual sites must be identified. These are given in Table 2.

WBS #	WBS Description	Facilities
402.02.03	Outer Tracker: Sensors	Brown, Rochester, Fermilab
402.02.04	Outer Tracker: Electronics	Fermilab, Princeton, Rutgers
402.02.05	Outer Tracker: Modules	Brown, Fermilab, Princeton, Purdue, Rutgers
402.02.06	Outer Tracker: Mechanics	Fermilab
402.02.07	Outer Tracker: Integration	Fermilab
402.04.03	Endcap Calorimeter: Sensors	Brown, Fermilab, Texas Tech
402.04.04	Endcap Calorimeter: Modules	Carnegie Mellon, Texas Tech, UC Santa Barbara
402.04.05	Endcap Calorimeter: Cassettes	Fermilab
402.04.06	Endcap Calorimeter: Backing Hadronic	Fermilab, FSU, Maryland, NIU, Rochester
402.04.07	Endcap Calorimeter: Electronics and Services	Fermilab, Minnesota
402.06.03	Trigger / DAQ: Cal Trigger	Wisconsin
402.06.05	Trigger / DAQ: Correlator Trigger	Wisconsin
402.06.06	Trigger / DAQ: DAQ	Fermilab, CERN
402.08.03	Timing Layer: Barrel Timing Layer	Virginia, Caltech, KSU, CERN
402.08.04	Timing Layer: Endcap Timing Layer	Fermilab, Nebraska, Kansas

Table 2: Major work or assembly sites for the U.S. CMS HL-LHC detector upgrade project.

4.3 Decontamination and Decommissioning

The Upgrade Project will maintain information necessary for future decontamination and decommissioning (D&D) if there is an expectation that D&D will be done under the aegis of the project. Disposition of instruments or components after they are no longer used in operations at CERN will be governed by MOUs among the institutions managing CMS. However, CERN has agreed to take ownership of potentially hazardous or irradiated materials at the end of the project and dispose of them according to Swiss and French regulations. Any additional necessary disposal of equipment returned to Fermilab will be done in accordance with the provisions of FESHM, Chapter 8021. Universities will dispose of equipment returned to them in accordance to their local requirements.

5.0 Conclusions

It is the intent of the HL-LHC CMS Detector Upgrade Project management that the technical and scientific goals of the project be achieved in a safe and environmentally sound manner. This document summarizes a variety of potential ES&H hazards that might be encountered in the construction and testing of the Project at Fermilab or university construction sites. The conclusion of the project management is that all major hazards have been identified and can be addressed by the means discussed here and in the references below.

6.0 Attachment A - Hazard Analysis Worksheets

This attachment presents the results of the Hazard Analysis process. The data are organized according to hazard type. Presented are the initiating event, the consequences, and the risk classification. Comments and a listing of the hazard mitigation measures in place are provided for each entry. The Risk Classification was performed using QAM 12030[1] as a guide.

HAZARD: Mechanical Hazard – Heavy equipment

HAZARD INITIATOR: Unsafe practices, equipment failure.
HAZARD CONSEQUENCE: Personnel injury, equipment damage, program delay.
COMMENTS: Special frames and carts are being designed to manipulate the endcap calorimeter cassettes. Workers will additionally need to use the crane. Proper training is mandatory.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY		
	☒ Likely	☐ Occasional
	☐ Probable	☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- Frame designs for manipulating cassettes.

MITIGATING FACTORS (OPERATIONAL)

- Only trained personnel are allowed to operate the rotating frames and the crane needed to manipulate the cassettes.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY		
	☐ Likely	☐ Occasional
	☐ Probable	☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Mechanical Hazard – Kinetic Energy

HAZARD INITIATOR: Unsafe practices, equipment failure.
HAZARD CONSEQUENCE: Personnel injury, equipment damage, program delay.
COMMENTS: Operation of hand held power tools and manual tools as well as rotating machinery operations.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY	☐ Likely	☒ Occasional
	☐ Probable	☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- Equipment safety guards, NRTL-listed power tools.

MITIGATING FACTORS (OPERATIONAL)

- Only trained personnel are allowed to operate power tools and rotating machinery.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY	☐ Likely	☐ Occasional
	☐ Probable	☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Electrical

HAZARD INITIATOR: Contact with energized equipment, electrical shock/arc flash from exposed conductors, defective equipment, substandard equipment, improper procedure.
HAZARD CONSEQUENCE: Personnel injury, equipment damage, program delay.
COMMENTS: Both commercially available and custom designed equipment will be used for sensor and electronics testing.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☒ Occasional ☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- All equipment meets applicable NEC and NEMA codes and FNAL safety requirements.

MITIGATING FACTORS (OPERATIONAL)

- Administrative procedures in effect for all work on electrical equipment and systems. Lockout/tagout rules in effect. Electrical Safety Review for all new systems.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☐ Occasional ☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Fire Hazard

HAZARD INITIATOR: Unsafe practices, defective equipment, substandard equipment
HAZARD CONSEQUENCE: Personnel injury, property damage, program delay.
COMMENTS: The wiring and the electrical equipment used in sensor and electronics testing may present a fire hazard.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☒ Occasional ☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- Equipment designed to all applicable standards.

MITIGATING FACTORS (OPERATIONAL)

- Systems and operations will be reviewed by independent safety review committees. Operator training and adherence to standard procedures.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☐ Occasional ☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Toxic Materials

HAZARD INITIATOR: Unsafe practices
HAZARD CONSEQUENCE: Accidental exposure
COMMENTS: Chemicals used in Outer Tracker and Endcap Calorimeter construction (solvents, glues, epoxies) may have associated health hazards.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☒ Occasional ☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)
- Choose chemicals with the lowest toxicity possible, while maintaining efficiency and efficacy. Comply with all applicable regulations for handling and storing chemicals.

MITIGATING FACTORS (OPERATIONAL)
- Only trained personnel will work on Outer Tracker and Endcap Calorimeter construction.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☐ Occasional ☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Laser Hazard

HAZARD INITIATOR: Improper operation of machinery
HAZARD CONSEQUENCE: Personnel injury
COMMENTS: Lasers may be used in sensor testing.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☒ Occasional
☐ Probable ☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- Engineered Systems per ANSI Z136.1 (American National Standard for Safe Use of Lasers).

MITIGATING FACTORS (OPERATIONAL)

- Technical and safety training of personnel utilizing tools and equipment (FESHM 4260: Lasers).

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Occasional
☐ Probable ☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Electrostatic Discharge Damage

HAZARD INITIATOR: Unsafe practices
HAZARD CONSEQUENCE: Equipment damage
COMMENTS: Sensors and other electronic chips and boards are susceptible to damage from electrostatic discharge.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☒ Occasional ☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- Sensor and chip package design ensures that component handling is minimized.

MITIGATING FACTORS (OPERATIONAL)

- Proper ESD equipment is provided for all sensor and chip handling areas. Operator training and adherence to established procedures. Trained personnel conduct operations only.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☐ Occasional ☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Cryogenic Hazard

HAZARD INITIATOR: Unsafe practices
HAZARD CONSEQUENCE: Personnel injury or equipment damage
COMMETS: Two-phase CO_2 will be used in test stands for Outer Tracker, Endcap Calorimeter, and Timing Layer.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY		
	☐ Likely	☒ Occasional
	☐ Probable	☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- System design follows all applicable standards and best practices for cryogenic systems.

MITIGATING FACTORS (OPERATIONAL)

- An operational readiness review has been held by an independent safety committee before allowing operation of the CO_2 system[4]. Operator training and adherence to established procedures. Trained personnel conduct operations only.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY		
	☐ Likely	☐ Occasional
	☐ Probable	☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: CO_2 Toxicity/ Oxygen Deficiency Hazard

HAZARD INITIATOR: Unsafe practices

HAZARD CONSEQUENCE: Personnel injury

COMMENTS: The volume of CO_2 stored in the SiDet CO_2 test area may result in a CO_2 toxicity and oxygen deficiency hazard.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY		
	☐ Likely	☒ Occasional
	☐ Probable	☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- System design follows ASME B31.3 for normal fluid service.
- CO_2 hazard analysis has been completed and reviewed for the system. This follows the structure of a FESHM 4240 ODH analysis, but uses a modified fatality factor for CO_2 toxicity vs ODH; This analysis resulted in an equivalent risk to conventional ODH class 0.

- System has been equipped with ventilation fans, air flow monitors, and piping isolation valves all to limit CO2 exposure in the event of a leak.

MITIGATING FACTORS (OPERATIONAL)

- All personnel working in the Lab C cleanrooms receive CO_2 hazard training, which covers: CO_2 toxicity, permissible CO_2 concentration limits, the CO_2 system, location of evacuation alarms, and evacuation procedures.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY		
	☐ Likely	☐ Occasional
	☐ Probable	☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Radiation
HAZARD INITIATOR: Unsafe practices
HAZARD CONSEQUENCE: Personnel injury
COMMENTS: Possible use of small radioactive sources and of test beam for testing of sensors and electronics.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☒ Occasional ☐ Remote

RISK	☐ Critical	☒ High	☐ Moderate	☐ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- Fermilab test beams have been designed and reviewed to ensure safe operation with minimal exposure for personnel and environment. Use of standard sources that comply with Fermilab Radiological Control Manual.

MITIGATING FACTORS (OPERATIONAL)

- All activities conducted in compliance with the Fermilab Radiological Control Manual.
- Routine area monitoring of dose levels by passive dosimeters for neutrons and gammas.
- Radiological safety training, e.g. GERT, Radiation Worker, etc.
- Work planning and control procedures for work in radiation areas or with radioactive materials, ALARA designs and committee reviews, annual dose limits.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☒ High	☐ Moderate	☐ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☐ Occasional ☒ Remote

RISK	☐ Critical	☐ High	☒ Moderate	☐ Low	☐ Minimal

HAZARD: Environmental

HAZARD INITIATOR: Unsafe practices

HAZARD CONSEQUENCE: Release of oils, solvents, chemicals or radiation to the soil, groundwater, air or sanitary system.

COMMENTS: CO_2 used in cooling systems; water/glycol mixture used in sensor test cooling system.

RISK ASSESSMENT PRIOR TO MITIGATION

CONSEQUENCE	☐ High	☐ Moderate	☒ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☒ Occasional ☐ Remote

RISK	☐ Critical	☐ High	☐ Moderate	☒ Low	☐ Minimal

MITIGATING FACTORS (DESIGN)

- Systems designed following all applicable standards and regulations. Closed loop cooling systems.

MITIGATING FACTORS (OPERATIONAL)

- Only trained personnel will operate systems, following established operational rules. Systems have undergone (CO_2) or will undergo (sensor test box) operational readiness reviews.

RISK ASSESSMENT FOLLOWING MITIGATION

CONSEQUENCE	☐ High	☐ Moderate	☒ Low	☐ Minimal

PROBABILITY ☐ Likely ☐ Probable ☐ Occasional ☒ Remote

RISK	☐ Critical	☐ High	☐ Moderate	☐ Low	☒ Minimal

7.0 References

[1] QAM Chapter 12030, Risk Assessment:
http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=2646

[2] FESHM Chapter 2060 ("Work Planning and Hazard Awareness"): http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=525

[3] FNAL Testbeam SAD: https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=943

[4] CMS CO_2 Cooling Test Stand - Operational Readiness Clearance Information:
http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1349

CMS CO_2 Hazard Assessment: http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1348

CMS CO_2 Piping Note: http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1347

CMS CO_2 Test Stand Copper Piping Note: http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1409

CMS CO_2 Test Stand and the Hazards of Carbon Dioxide:
http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1476

Electrical Engineering Note - CMS CO_2 Test Stand:
http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1439

CMS CO_2 Half Disk Assembly Piping Note:
http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1490

CMS CO_2 Cooling Test Stand: Closeout Session:
http://ppd-docdb.fnal.gov/cgi-bin/ShowDocument?docid=1497

[5] U.S. CMS HL-LHC Upgrade Project Integrated Safety Management Plan:
https://cms-docdb.cern.ch/cgi-bin/DocDB/ShowDocument?docid=13395