

Experiment Safety Assessment Document
(ESAD)
for the Hall B CLAS12 RG-L Experiment

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Chapter 1

Introduction

This ESAD document describes the identified hazards of the experiment and the measures taken to eliminate, control, or mitigate them. This document is part of the CEBAF experiment review process as defined the Jefferson Lab ES&H manual, and will start by describing general types of hazards that might be present in any of the JLab experimental halls. The document then addresses the hazards associated with subsystems of the equipment in Experimental Hall B and their mitigation. Responsible personnel for each item are also noted. In case of life threatening emergencies call 911 and then notify the guard house at x5822 so that the guards can help the responders. This document does not attempt to describe the function or operation of the various subsystems. Such information can be found in the individual subsystem Operations Manuals.

Chapter 2

General Hazards

2.1 Radiation

CEBAF's high intensity and high energy electron beam is a potentially lethal direct radiation source. It can also create radioactive materials that are hazardous even after the beam has been turned off. There are many redundant measures aimed at preventing accidental exposure to personnel by the beam or exposure to beam-associated radiation sources that are in place at JLab. The training and mitigation procedures are handled through the JLab Radiation Control Department (RadCon). RadCon can be contacted as follows: For routine support and surveys, or for emergencies after-hours, call the RadCon cell phone at (757)-876-1743. For escalation of effort or for emergencies, contact the RadCon manager.

Radiation damage to materials and electronics is mainly determined by the neutron dose (photon dose typically causes parity errors and is easier to shield against). Commercial-off-the-shelf (COTS) electronics is typically robust up to neutron doses of about 10^{13} n/cm². If the experimental equipment dose as calculated in the RSAD is beyond this damage threshold, the experiment needs to add an appendix on "Evaluation of potential radiation damage" in the experiment-specific ESAD. There, the radiation damage dose, potential impact to equipment located in areas above this damage threshold, as well as the mitigating measures to be taken should be described.

2.2 Fire

Each of the experimental halls contains numerous combustible materials and flammable gases. In addition, they contain potential ignition sources, such as electrical wiring and equipment. General fire hazards and procedures for dealing with these are covered by JLab emergency management procedures. The JLab fire protection manager (Robert Myles) can be contacted at (757)-269-7571, Cell: (757)-270-9071.

2.3 Electrical Systems

Hazards associated with electrical systems are the most common risk in the experimental halls. Almost every subsystem requires AC and/or DC power. Due to the high current and/or high voltage requirements of many of these subsystems, they and their power supplies are potentially lethal electrical sources. In the case of superconducting magnets the stored energy is so large that an uncontrolled electrical discharge can be lethal for a period of time even after the actual power source has been turned off. Anyone working on electrical power in the experimental halls must comply with the Jefferson Lab ES&H manual and must obtain approval of one of the responsible personnel. The JLab electrical safety point-of-contact (Chad Bailey) can be reached at (757)-269-7052.

2.4 Mechanical Systems

There exist a variety of mechanical hazards in all experimental halls at JLab. Numerous electro-mechanical subsystems are massive enough to produce potential fall and/or crush hazards. In addition, heavy objects are routinely moved around within the experimental halls during reconfigurations for specific experiments.

Use of ladders and scaffolding must comply with the Jefferson Lab ES&H manual. As well, use of cranes, hoists, lifts, etc. must comply with the Jefferson Lab ES&H manual. Use of personal protective equipment to mitigate mechanical hazards, such as hard hats, safety harnesses, and safety shoes, are mandatory when deemed necessary. The JLab technical point-of-contact (Chad Bailey) can be contacted at (757)-269-7052.

2.5 Strong Magnetic Fields

Powerful magnets exist in all JLab experimental halls. Metal objects may be attracted by the magnet fringe field and become airborne, possibly injuring body parts or striking fragile components, resulting in a cascading hazard condition. Cardiac pacemakers or other electronic medical devices may no longer function properly in the presence of magnetic fields. Metallic medical implants (non-electronic) may be adversely affected by magnetic fields. Loss of information from magnetic data storage devices such as tapes, disks, and credit cards may also occur. Contact Jennifer Williams at (757)-269-7882, in case of questions or concerns.

2.6 Cryogenic Fluids and Oxygen Deficiency Hazard

Cryogenic fluids and gases are commonly used in the experimental halls at JLab. When released in an uncontrolled manner these can result in explosion, fire, cryogenic burns, and the displacement of air, resulting in an oxygen deficiency hazard (ODH) condition. The hazard level and associated mitigation are dependent on the subsystem and cryogenic fluid. However, they are mostly associated with cryogenic superconducting magnets and cryogenic target systems. Flammable cryogenic gases used in the experimental halls include hydrogen and deuterium, which are colorless, odorless gases and, hence, not easily detected by human senses. Hydrogen air mixtures are flammable over a large range of relative concentrations from 4% to 75% H_2 by volume. Non-flammable cryogenic gases typically used include He and nitrogen. Contact Jennifer Williams at (757)-269-7882 in case of questions or concerns.

2.7 Vacuum and Pressure Vessels

Vacuum and/or pressure vessels are commonly used in the experimental halls. Many of these have thin aluminum or Kevlar/Mylar windows that are close to the entrance and/or exit of the vessels or beampipes. These windows burst if punctured accidentally or can fail if significant over-pressure were to exist. Injury is possible if a failure were to occur near an individual. All work on vacuum windows in the experimental halls must occur under the supervision

of appropriately trained JLab personnel. Specifically, the scattering chamber and beamline exit windows must always be leak checked before service. Contact Tim Michalski (757)-269-6523 for vacuum and pressure vessel issues.

2.8 Hazardous Materials

Hazardous materials in the form of solids, liquids, and gases that may harm people or property exist in the JLab experimental halls. The most common of these materials include lead, beryllium compounds, and various toxic and corrosive chemicals. Material Safety Data Sheets (MSDS) for hazardous materials in use in the experimental hall are available from the hall Safety Wardens. These are being replaced by the new standard Safety Data Sheets (SDS) as they become available in compliance with the new OSHA standards. Handling of these materials must follow the guidelines of the ES&H manual. Machining of lead or beryllium, which are highly toxic in powdered form, requires prior approval of the ES&H staff. Lead Worker training is required in order to handle lead in the experiment halls. In case of questions or concerns, the JLab hazardous materials specialist (Scott Conley) can be contacted at (757)-269-7308.

2.9 Lasers

High power lasers are often used in the experimental areas for various purposes. Improperly used lasers are potentially dangerous. Exposure to laser beams at sufficient power levels may cause thermal and photochemical injury to the eye, resulting in retina burns and blindness. Skin exposure to laser beams may induce pigmentation, accelerated aging, or severe skin burns. Laser beams may also ignite combustible materials creating a fire hazard. At JLab, lasers with power higher than 5 mW (Class IIIB) can only be operated in a controlled environment with proper eye protection and engineering controls designed and approved for the specific laser system. Each specific laser system shall be operated under the supervision of a Laser System Supervisor (LSS) following the Laser Operating Safety Procedure (LOSP) for that system approved by the Laboratory Laser Safety Officer (LSO). The LSO (Jennifer Williams) can be reached at (757)-269-7556.

Chapter 3

Hall B-Specific Equipment

3.1 Overview

The Hall B subsystems included in this chapter are considered part of the End-station Experimental Equipment for the RG-L (ALERT) experiment. Many of these subsystems impose similar hazards, such as those associated with magnetic fields and power supplies, high voltage systems, cryogenic systems, and vacuum systems. Note that a specific subsystem may have many unique hazards associated with it. For each major system, the hazards, mitigations, and responsible personnel are noted.

The material in this chapter is a subset of the material in the Hall B subsystem Operations Manuals and is only intended to familiarize people with the hazards and responsible personnel for these systems. In no way should it be taken as sufficient information to use or operate this equipment.

3.2 Detector Checkout System

The Hall B equipment readiness for the beam run will be done using the CEBAF Hot Checkout system (HCO) [1]. Each detector system has its own subsystems and items that have to be checked and signed off by the appropriate groups. The systems that have been checked and signed as ready for beam will be indicated by a green “thumbs up”. Subsystems that are still waiting for readiness check-out and approval will be indicated with red crosses.

In order to make sure that hall equipment that should be tied into the

machine Fast Shutdown (FSD) system has been properly checked, the Hall Work Coordinator must be notified by e-mail prior to the end of each installation period by the system owner that the checks have been performed in conjunction with accelerator operations (*i.e.* checking that the equipment’s signals will in fact cause an FSD). These notifications will be noted in the Work Coordinator’s final checklist as having been done. System owners are responsible for notifying the Work Coordinator that their system has an FSD tie-in so it can be added to the checklist.

The hall will get permission to run beam only after all systems tied to the delivery of the beam to the designated destination are signed off. At that point the main Hall B system will indicate “Ready” in the HCO tree.

3.3 Beamline

The control and measurement equipment along the Hall B beamline consists of various elements necessary to transport the beam with the required specifications onto the production target and the beam dump, and simultaneously to measure the properties of the beam relevant to the successful implementation of the physics program in Hall B.

The beamline in the hall provides the interface between the CEBAF accelerator and the experimental hall. All work on the beamline must be coordinated with both the Physics Division and the Accelerator Division in order to ensure safe and reliable transport of the electron beam to the dump. The Accelerator Division has the primary responsibility of delivering the electron beam to the experimental target and designated dumps.

3.3.1 Hazards

Along the beamline various hazards can be found. These include radiation areas, vacuum windows, high voltage, and magnetic fields.

3.3.2 Mitigations

All magnets (dipoles, quadrupoles, sextupoles, beam correctors) and beam diagnostic devices (BPMs, scanners, beam loss monitors, viewers) necessary to transport and monitor the beam are controlled by the Machine Control Center (MCC) and/or Hall B personnel through EPICS [2]. The detailed

operational procedures for the Hall B beamline are essentially the same as those for the CEBAF machine and beamline.

Personnel who need to work near or around the beamline should keep in mind the potential hazards:

- Radiation “Hot Spots” - marked by an ARM or RadCon personnel,
- Vacuum in beamline elements and other vessels,
- Thin-windowed vacuum enclosures (*e.g.* the scattering chamber),
- Electric power hazards in the vicinity of magnets, and
- Conventional hazards (fall hazard, crane hazard, etc.).

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

These hazards are noted by signs and the most hazardous areas along the beamline are roped off to restrict access when operational (*e.g.* around the magnets). Signs are posted by RadCon for any hot spots. Surveys of the beamline and surrounding areas will be performed before any work is done in these areas. The connection of leads to magnets have plastic covers for electrical safety. Any work around the magnets will require de-energizing the magnets. Energized magnets are noted by red flashing beacons. Any work on the magnets requires the “Lock and Tag” procedures [3] by appropriately trained and certified electrical workers. Additional safety information can be obtained from the ES&H Manual [3].

3.3.3 Responsible Personnel

The beamline requires both Accelerator and Physics Division personnel to maintain and operate (see Table 3.1). It is very important that both groups stay in contact with each other to coordinate any work on the Hall B beamline.

3.4 Vacuum System

The Hall B vacuum system for the RG-L (ALERT) experiment consists of two segments: the beam transport line to the experimental target, consisting of 1.5 in to 2.5 in diameter beampipes and the vacuum beamline to the

Name	Dept.	Phone	email	Comments
Expert on call		757-303-3996		1st contact
E. Pasyuk	Hall B	x6020	pasyuk@jlab.org	2nd contact
M. Tiefenback	Accel.	x7430	tiefen@jlab.org	beamline optics
K. Price	Accel.	x7067	kprice@jlab.org	Contact to OPS

Table 3.1: Responsible personnel for the Hall B beamline.

Hall B electron dump consisting of 2 in to 6 in diameter beampipes. The vacuum spaces are physically isolated from each other and the vacuum level can be monitored independently using cold cathode gauges. The vacuum in the system is provided by a set of roughing, turbo, and ion pumps, and is maintained at a level of better than 10^{-5} Torr.

3.4.1 Hazards

Hazards associated with the vacuum system are due to rapid decompression in case of a window failure. Loud noises can cause hearing loss.

3.4.2 Mitigations

All personnel working in the vicinity of the entrance and exit windows are required to wear hearing protection. Warning signs must be posted in that area. In addition, all vacuum vessels and piping are designed as pressure vessels. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.4.3 Responsible Personnel

The vacuum system will be maintained by the Hall B Engineering Group (see Table 3.2).

Name	Dept.	Phone	email	Comments
Engineering on call	Hall B	757-748-5048		1st contact
D. Insley	Hall B	757-897-9060	dinsley@jlab.org	2nd contact

Table 3.2: Personnel responsible for the Hall B vacuum system.

3.5 Target System

The RG-L (ALERT) experiment will use a variety of gas targets (hydrogen, deuterium, and helium) at room temperature at up to 4.6 atm pressure (= 68 psig). The target cell is a 45-cm-long aluminum-coated Kapton straw of 0.6 cm diameter and 50 μm wall thickness. The straw has entrance and exit windows of 30- μm thick aluminum. The target will be mounted inside the center bore of the ALERT detector along the beamline. There will be a 1 cm air gap between the upstream beamline and the ALERT target. The upstream beam pipe includes a 30 μm thick aluminum window. ALERT will have a helium extension tube on the downstream end with a 30 μm aluminum window. There will be a 4 cm air gap between this window and the 75 μm thick window on the downstream beam pipe. The details of all components, such as windows and cells, are shown on the beamline drawing, including thicknesses and locations. These drawings can be found at Ref. [4].

3.5.1 Hazards

The main hazard is a potential rupture of the target cell or the target entrance and exit windows. If the target is filled with ^4He at the time, the only hazard would be a loud noise and potential damage to the ALERT detector surrounding the target due to a pressure shock. If the target is filled with ^1H or ^2H , an additional hazard will be the presence of these flammable gases within the ALERT detector environment. The total gas volumes involved are too small to create a ODH risk.

3.5.2 Mitigations

The design and construction of the gas target is in accordance to ASME B31.3 process piping code, except downstream of the isolation valve. This section includes the target cell and is qualified by equivalent measures. These include limiting the amount of flammable gas in this section and preventing excess flow into this section from the buffer volume in case of a sudden pressure loss due to a rupture of the target cell or its windows. A flame arrestor prevents the ignition of flammable gas upstream of this section (upstream of the isolation valve). Note that in case of a target straw rupture, the flammable gas is released into another gas enclosure that is filled with inert

gas (80% He/20% CO₂) and has a continuous flow to renew the gas slowly (rate \sim few liters/hr).

During operation the target straw and the thin entrance and exit windows are surrounded by the ALERT detector and are therefore difficult to access. The target will only be filled with gas in excess of 1 atm pressure when installed inside the CLAS12 solenoid.

Two H₂/D₂ gas detectors are installed near the target location, one above the right hand side of the electronics rack and another above the cryostat. In case of a detected leak, the control system will immediately shut off the supply of gas to the target.

A pressure sensor is mounted downstream of the isolation valve to detect a sudden loss of pressure and immediately shut off the gas supply. The quantity of flammable gas (H₂ or D₂) downstream of the isolation valve is less than 1000 ft lbs in energy (1355 J). The ratio of energy per volume for hydrogen or deuterium is 14.5 J/cm³. This includes chemical heat of combustion (13 J/cm³) and mechanical explosion energy (1.5 J/cm³, Brode equation). For the limit of 1355 J this corresponds to 13.3 cm³ of deuterium (or hydrogen) gas at 7 atm (93.4 cm³ at 1 atm).

This volume limit in the section qualified by equivalent measures will be achieved by limiting the volume of the target cell plus the capillary supply tubing up to the isolation valve to 13.3 cm³. To limit the amount of gas flow into the target cell, the supply tubing inner diameter will be capillary and an excess flow valve will limit the flow in case of sudden loss of pressure in the target cell due to bursting.

- The area shall be posted “Danger Flammable Gases. No Ignition Sources”.
- Combustibles and ignition sources shall be minimized within 10 ft or 3 m of target’s gas handling equipment and piping.

The target does not operate in a confined space, and the total quantity of hydrogen/helium in the system is under 1000 standard liters. This presents a negligible oxygen deficiency risk in Hall B and therefore is a class-0 ODH installation.

Hydrogen shall be loaded into the system by qualified personnel only, and those personnel shall follow approved operational gas handling procedures. Upon loss of target gas pressure, the control system shall automatically shut off the gas supply.

The target control software includes numerous alarms (temperature, pressure, vacuum, etc.) to alert users to potential problems.

3.5.3 Responsible Personnel

The target system will be maintained by the Hall B Engineering Group (see Table 3.3).

Name	Dept.	Phone	email	Comments
Engineering on call	Hall B	757-748-5048		1st contact
D. Insley	Hall B	757-897-9060	dinsley@jlab.org	2nd contact
M. Cook	Hall B	757-971-0150	mcookiv@jlab.org	3rd contact

Table 3.3: Personnel responsible for the CLAS12 ALERT target system.

3.6 Hall B Gas System

The Hall B gas systems supply gas to the following detectors at the indicated pressures in Hall B:

1. Forward Drift Chambers
 - 10% CO₂ in Argon at 0.075 inch wc
 - N₂ purge for external HV components at atmospheric pressure
2. LTCC
 - C₄F₁₀ at 1.0 – 4.0 inch wc
 - N₂ purge for C₄F₁₀ recovery at 1.0 – 4.0 inch wc
3. ALERT
 - 80% He + 20% CO₂ at 1060 mbar
4. RICH
 - N₂ purge for aerogel at atmospheric pressure
 - Air cooling purge supply for enclosed electronics package at 5-55 psi, discharges to atmosphere

- Air compressor output at 112 psi

5. HTCC

- CO₂ purge at 0.150 inch wc

6. FT

- N₂ purge for calorimeter at atmospheric pressure

The Hall B Gas Controls consists of a National Instruments cRIO based controls system that supplies and monitors gas flow to the three baseline detectors (DC, HTCC, LTCC). Additionally, it also controls and monitors gas supply to three non-baseline detectors (ALERT, FT, RICH).

The system consists of four stations strategically located in the hall and Gas Shed that are linked via the Slow Controls network. Each station consists of a cRIO controls chassis, a custom interface chassis, and a touch screen monitor. All gas system instrumentation equipment (transducers, mass flow controllers, valve drivers, etc.) receive operational power from supplies that are internal to the custom interface chassis.

The main controls interface for the system is located in the Gas Shed, where all functions of the system are controlled. All system chassis are electrically grounded to the racks, and each contains an overcurrent protection fuse.

3.6.1 Hazards

The following cryogenics are used at the 96B Gas Shed at the following pressures:

- Liquid Argon - 175 – 200 psi
- Liquid Nitrogen - 45 psi
- Liquid CO₂ - 160 – 300 psi

The following gases are produced from cryogen boil off:

- Ar - 160 – 200 psi
- CO₂ - 160 – 200 psi

- N₂ - 35 psi

The following gases are used at the 96B Gas Shed at the following pressures:

- Ar - 40 – 200 psi
- CO₂ - 15 – 200 psi
- CF₄ - 40 psi
- C₄F₁₀ - 4 – 50 psi
- C₄H₁₀ - 40 psi
- N₂ - 35 psi

The following gas mixtures are produced at the following pressures:

- 10% CO₂ in Argon - 100 psi
- 10% C₄H₁₀ in Argon - 15 psi (not used for RG-L)
- 10% CF₄ 10% C₄H₁₀ in Argon - 15 psi (not used for RG-L)

The ALERT gas mixture is non-flammable:

- 80% He 20% CO₂ - 1060 mbar

The following gases and gas mixtures are sent to Hall B at the following pressures:

- 10% CO₂ in Argon - < 5 psi
- 10% C₄H₁₀ in Argon - 15 psi (not used for RG-L)
- 10% CF₄ 10% C₄H₁₀ in Argon - 15 psi (not used for RG-L)
- N₂ - 35 psi
- CO₂ - 15 psi
- C₄F₁₀ - 4 – 8 psi

3.6.2 Mitigations

The 1500 gallon liquid-argon dewar and 160 liter liquid CO₂ dewar are used for gas supply only. The dewars have relief valves preventing overpressure.

Liquid nitrogen is used in both gas and liquid states. The 1500 gallon LN₂ dewar has a relief valve preventing overpressure. N₂ gas is used as a purge gas for detectors and other equipment. The purge flow is controlled by mass flow controllers or flow rotameters and discharges to the atmosphere. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).
Detectors:

1. The Drift Chambers have both active and passive pressure protection. Pressure relief bubblers attached to the detector exhaust manifolds passively prevent the pressure from exceeding 0.125 inch wc pressure or vacuum. The active pressure protection system consists of a pressure transducer, process controller, and solenoid valves that isolate the detectors from the gas system if the pressure goes outside the 0.025 – 0.125 inch wc band. There are EPICS-based alarms to alert personnel of high or low pressure and flows.

The N₂ purge for the endplate electronics is controlled by rotometers in the 96B Gas Shed. This purge discharges at atmospheric pressure.

2. The ALERT AHDC drift chambers is designed to operate at a constant internal pressure. The gas system was designed with both active and passive pressure protection. Pressure relief bubblers attached to the detector exhaust manifolds passively prevent the pressure from exceeding 0.125 inch wc pressure or vacuum. The active pressure protection system consists of a pressure transducer, process controller, and solenoid valves that isolate the detectors from the gas system if the pressure goes outside the 0.025 – 0.125 inch wc band. There are EPICS-based alarms to alert personnel of high or low pressure and flows.
3. The LTCC has both active and passive pressure protection. Pressure relief bubblers attached to the detector exhaust passively prevent the pressure from exceeding 4.00 inch wc or vacuum. The active pressure protection system consists of a pressure transducer, process controller, and solenoid valves that isolate the detector from the gas system if pressure goes outside the 1.00 – 3.00 inch wc pressure band. There are EPICS-based alarms to alert personnel of high or low pressures.

Liquid N₂ is used to cool the C₄F₁₀ distillation unit in the 96B Gas Shed in order to condense and recover C₄F₁₀ for reuse. The distillation unit has a relief valve preventing overpressure. The N₂ discharge flows through heat exchangers and vents to atmosphere at ambient temperature and pressure.

4. The MVT gas mixing system supplies gas to the MVT and FT gas control chassis. The system has relief valves that prevent the gas supply and mixed gas pressure from exceeding 45 psi. A flammable gas detector is used at the valve panel in the 96B Gas Shed to warn of gas leakage. There are EPICS-based alarms to alert personnel of high or low pressure.
5. The FT calorimeter has a N₂ purge to prevent condensation that discharges to the atmosphere at ambient pressure. There are EPICS-based alarms to alert personnel of high or low flow.
6. The HTCC CO₂ purge flow is controlled by a MFC. Pressure relief bubblers attached to the detector volume, passively prevent pressure from exceeding 0.125 inch wc or vacuum. There are EPICS-based alarms to alert personnel of high or low pressure and flows.
7. The RICH air cooling supply has pressure relief valves at the compressor output, at the air receiver, and at the rotameter input to prevent an overpressure condition. The N₂ purge for the aerogel discharges to the atmosphere. There are EPICS-based alarms to alert personnel of high or low pressure.

3.6.3 Responsible Personnel

Individuals responsible for the gas systems are (see Table 3.4):

Name	Dept.	Phone	email	Comments
Engineering on call	Hall B	757-748-5048	—	1st contact

Table 3.4: Personnel responsible for the CLAS12 gas system.

3.7 DAQ and Trigger

The DAQ and Trigger systems consists of multiple VXS, VME, and other crates housing various readout modules such as FADC250 ADCs, TDC1190 and TDC1290 TDCs, 16-channel discriminators, trigger modules, and various other units. These crates are powered by industrial power supplies, most of them produced by Wiener, Germany.

The computer cluster contains about 30 computers located mostly in the Hall B Counting House, but some computers are installed in the hall. The network consists of about 20 switches and routers located in both the Counting House and in the hall. Backup power is provided by three large UPS devices, one in the Counting House and two in the hall.

Signal and power transmission is handled by a large number of copper cables interconnecting the various electronics modules and detector elements. A smaller number of optical cables are employed to transmit synchronization, time-keeping signals, and various other communication services throughout the experimental hall.

3.7.1 Hazards

Hazards to personnel include the electric power supplied to the electronic components. There is also a fire hazard associated with cabling throughout the experimental hall.

3.7.2 Mitigations

All of the crates and chassis are commercially available and are powered from 208 V AC. These meet stringent safety requirements set by various qualified agencies such as UL and TUV. Internal fans help manage thermal loads and several internal controls are implemented to provide limits on over-current and over-temperature excursions. All structures are grounded. Additionally, aluminum blank panels have been installed to limit access to the backplane on the rear of the chassis and on the front side where slots are unused. All power distribution is power-limited for current and voltage and interlocked via the Slow Controls system. All cables are NEC UL rated CL2 or better and conform to the 2011 edition of the NEC NFPA70 code requirements for fire prevention and thus, limit flame propagation in case of fire. Additionally, all cables are shielded and referenced to ground for added personnel and

equipment safety. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

There are possible electrical hazards if a malfunctioning electronics component is replaced. The associated task hazard analysis concluded that the consequence level is low, the probability level is low, and the risk code is 1. The mitigation for these electrical jobs is to place the equipment in Mode 0 (de-energized) when replacing or repairing hardware during routine maintenance.

3.7.3 Responsible Personnel

Individuals responsible for the DAQ and Trigger systems are (see Table 3.5):

Name	Dept.	Phone	email	Comments
S. Boyarinov	Hall B	757-232-6221	boiarino@jlab.org	1st contact

Table 3.5: Personnel responsible for the CLAS12 DAQ and Trigger system.

3.8 High Threshold Cherenkov Counter

The HTCC is a single unit detector that covers the entire working acceptance of CLAS12 in the forward direction. It is mounted on a special cart between the Central Detector and the Drift Chambers. The detector is connected to several systems: electronics including high and low voltage power supplies, gas supply line, and on-line monitoring and control equipment that provides the current status of the detector. The HTCC has 48 channels of Cherenkov light detection. For periodic checks and calibration, the detector is equipped with fast a Light Monitoring System. The HTCC is filled with dry CO₂ gas at room temperature and low positive differential pressure. It is directly connected to a CO₂ gas line and must be continuously purged to keep the relative humidity inside the detector below 3%. All controls and operations of the HTCC can be performed remotely.

3.8.1 Hazards

- 1). Operating high/low voltage power source.
- 2). ODH hazard when checking and/or maintaining components inside the

HTCC containment vessel.

- 3). ODH hazard in case of HTCC entry or exit composite windows failure (rupture or separation due to fatigue of the epoxy glue joints) leading to significant CO₂ gas leaks.
- 4). Hazard of rupture of the HTCC entry or exit composite windows leading to a sudden release of CO₂ gas with energy accumulated in the HTCC containment vessel.
- 5). Any mechanical shocks to the HTCC while moving the system on its cart in the hall.

3.8.2 Mitigations

Since the power of electrical equipment used in HTCC operations is low (less than 20 W), the electrical hazard is low and may occur only if connections are changed when the power supply is on. Gas system hazards are also low because the working gas is non-toxic, non-flammable, and is used at low temperature and differential pressure. The volume of the detector is negligible as compared with the volume of Hall B. Damage of the detector during movement or alignment must be excluded by certified personnel performing tasks strictly following procedures established by the Hall B Engineering Group. All personnel are expected to work in accordance with the ePAS and procedure “Testing and Running of the High Threshold Cherenkov Counter of the CLAS12 Spectrometer in the Experimental Hall B”. The highest risk code after mitigation is 1. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.8.3 Responsible Personnel

Individuals responsible for the HTCC system are (see Table 3.6):

Name	Dept.	Phone	email	Comments
Expert on call		757-344-7174		1st contact
Y. Sharabian	JLab	757-565-0619	youris@jlab.org	2nd contact

Table 3.6: Personnel responsible for the CLAS12 HTCC system.

3.9 Drift Chambers

The CLAS12 Drift Chamber (DC) system is comprised of 18 separate chambers. There are three types: “region 1”, “region 2”, and “region 3” depending on location upstream, within, or downstream of the CLAS torus magnet. Each chamber has wires arranged in two superlayers of 6 layers by 112 wires. The gas system supplies mixed, clean, pressure-controlled argon/CO₂ gas to each of the 18 drift chambers. The on-chamber amplifier and readout boards are called “signal translator boards” (STBs). There are 7 such boards per superlayer. They distribute low voltage (LV) power to pre-amplifiers located on the board, one for each sense wire. The pre-amps are placed in groups of 16, with six such groups per board. There is an individual fuse for every group of sixteen. Thirty-four conductor signal cables (16 twisted-pair signals) connect each STB group of 16 pre-amps with one connector on the drift chamber readout board (DCRB). High voltage (HV) is supplied to the wires by on-chamber “high-voltage translator boards” (HVTBs), located on the opposite endplate from the STBs. The high voltage is supplied to the HVTBs by a chain of cables connecting the HV crates to the “high voltage distribution boards” (HVDBs) and from there by cables to the HVTBs.

3.9.1 Hazards

Hazards to personnel include the high voltage supplied to the wires and the low voltage that powers the on-chamber pre-amplifiers. Hazards to the drift chambers themselves include damage to the gas windows should the pressure deviate more than a few psi from atmospheric.

3.9.2 Mitigations

Electrical hazards:

- High Voltage: high voltages up to 2000 V are used routinely for all detectors. Mitigation: very low current limits (40 μ A) are set. All mechanical structures are properly grounded. There are possible electrical hazards if a malfunctioning HV board is replaced. The associated ePAS concluded that the risk is low, but any work on this system must be covered by ePAS Permit to Work(s) (PTW).

- Low Voltage: In order to power up the on-chamber electronics, we use low voltage at 7 V with 50 A per supply (1 supply per chamber). Mitigation: voltage is low enough not to be a danger to personnel. All mechanical structures are properly grounded. All cables and connectors are certified for this rating and shielded. To protect against possible over-heating of the on-chamber pre-amplifier boards, each individual conductor (positive and neutral return) is fused; with the fuses located in a fuse panel with a red LED signaling a blown fuse. If a fuse is removed and/or replaced there is no risk to personnel because of the low voltage.

Gas system hazards:

- Personnel: because most of the system operates very close to atmospheric pressure there is no hazard to personnel in the hall due to pressure. The gas is non-toxic and non-flammable. Because of the large volume of the hall and the location of the chambers in the main open area of the hall, there is no ODH hazard to personnel.
- Detectors: there is a potential danger to the chamber gas windows if the pressure in the chamber differs from atmospheric by one psi. This is mitigated during standard operation by our pressure-difference control system with fail-safe over-pressure and under-pressure bubblers providing an additional level of safety.

3.9.3 Responsible Personnel

Individuals responsible for the DC system are (see Table 3.7):

Name	Dept.	Phone	email	Comments
Expert on call		757-748-5048		1st contact
F. Hauenstein	Hall B	757-746-3395	hauenst@jlab.org	2nd contact
M. Cook	Hall B		mcookiv@jlab.org	3rd contact

Table 3.7: Personnel responsible for the CLAS12 DC system.

3.10 ALERT Detector

The ALERT detector system consists of two subsystems: a drift chamber (AHDC) and a time-of-flight scintillator detector (ATOF). In the following, details are reported for these subcomponents.

3.10.1 ALERT Hyperbolic Drift Chamber

The ALERT Hyperbolic Drift Chamber (AHDC) is a cylindrical drift chamber placed along the beamline within the CLAS12 5 T solenoid. It consists of 3026 wires arranged in 8 layers of sense wires (totalling 576 sense wires) arranged along the beamline alternating with $\pm 10^\circ$ stereo angle. Between each layer of sense wires are strung layers of field wires. The gas system supplies mixed, clean, pressure-controlled 80% He/20% CO₂ gas. The chamber is connected via 2-m-long, 64-channel multi-conductor signal cables to front-end readout boards located on the ALERT detector installation cart. The 512-channel readout boards each contain 8 64-channel DREAM ASIC preamplifier/shapers. The high voltage (HV) is supplied to the on-chamber HV adapter boards from the local HV crate. The sense wires are at positive HV and the field and guard wires are grounded.

3.10.2 Hazards

There are four hazards to personnel associated with the ALERT AHDC system related to i) the high voltage (HV) system supplied to the wires, ii) the LV system that powers the pre-amplifiers, iii) the solenoid magnetic field, and iv) access to the detector during testing operations. The hazard to the AHDC hardware includes damage to the gas enclosure should the pressure deviate more than a few psi from atmospheric.

3.10.3 Mitigations

Electrical hazards:

- High Voltage: high voltages up to 2000 V are used routinely for all detectors. Mitigation: very low current limits (40 μ A) are set. All mechanical structures are properly grounded. There are possible electrical hazards if a malfunctioning HV board is replaced. The associated

ePAS concluded that the risk is low, but any work on this system must be covered by ePAS Permit to Work(s) (PTW).

- Low Voltage: In order to power up the pre-amplifiers, we use low voltage at < 10 V with 50 A per supply. Mitigation: power is low enough not to be a danger to personnel. All mechanical structures are properly grounded. All cables and connectors are certified for this rating and shielded. The amplifiers are housed within the JLab-design front-end electronics units are suitably protected from over-heating, over-current, and over-voltage.

Gas system hazards:

- Personnel: because most of the system operates very close to atmospheric pressure there is no hazard to personnel in the hall due to pressure. The gas is non-toxic and non-flammable. Because of the large volume of the hall and the location of the chambers in the main open area of the hall, there is no ODH hazard to personnel.
- Detectors: there is a potential danger to the ALERT detector gas enclosure if the pressure in the detector differs from atmospheric by one psi. This is mitigated during standard operation by our pressure-difference control system with fail-safe over-pressure and under-pressure bubblers providing an additional level of safety.

The ALERT detector is positioned in the magnetic field of the CLAS12 solenoid. When the solenoid is energized to its full nominal current, the central field strength is 5 T and the field strength at upstream end of the detector is at the level of 1 kG. This field level presents a possible hazard to both personnel and to ALERT detectors (as well as the other detectors in located about the solenoid). As such no service work on the ALERT detector is to take place when the solenoid is energized.

During testing or repairs with the solenoid off, it is possible to access the front-end electronics racks and the upstream end of the ALERT detector. If there is need for the use of ladders or platforms, there are fall hazards that must be mitigated. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.10.4 Responsible Personnel

Individuals responsible for the ALERT AHDC system are (see Table 3.8):

Name	Dept.	Contact	Comments
Expert on call		757-329-4844	1st contact
G. Charles	Orsay	<code>gabriel.charles@ijclab.in2p3.fr</code>	2nd contact
R. Dupré	Orsay	<code>raphael.dupre@ijclab.in2p3.fr</code>	3rd contact

Table 3.8: Personnel responsible for the ALERT AHDC system.

3.10.5 ALERT Time-of-Flight System

The ALERT Time-of-Flight detector (ATOF) consists of 15 modules mounted parallel to the beamline that connect to a support framework radially outward of the AHDC. Each ATOF module includes a single thin scintillator bar along the length of the module on its inside face backed by 10 thicker scintillator wedges. The bars and wedges are read out by silicon photomultipliers (SiPMs) glued to the scintillators. The ATOF front-end electronics for each module consists of a hybrid system incorporating both JLab-designed Petrioc2A and NALU Electronics ASOC boards. These boards are used to shape the signals and provide both energy (ADC) and timing (TDC) information. The front-end electronics located on the ALERT installation cart also contact signal distribution boards for power, clock, and timing signals.

3.10.6 Hazards

There are three hazards associated with the ATOF system related to i) the low voltage system used to energize the ATOF SiPMs, ii) the solenoid magnetic field, and iii) access to the counters during testing operations.

3.10.7 Mitigations

The low voltage power supply for the ATOF counters has typical settings for each channel are: $V = 100$ V. This supply is located in the electronics racks attached to the ALERT installation cart. There are two hazards associated with the LV system when energized that must be mitigated. The first is the electrical hazard and the second is the potential damage to SiPMs if a light leak is introduced in the counter wrapping material when the PMT is energized.

The electrical hazard associated with the LV system would be to receive an electrical shock. However, the design of the LV system for the ATOF is

such that the chance to receive an electrical shock is minimal. The electrical hazards are mitigated by the use of properly rated power cables that are terminated at the SiPM end and the power supply end. As well, the supplies are grounded to their electronics racks. The bigger issue would be damage to a SiPM if improper contact with the counter surface were to occur that introduced a sizable light leak in the counter wrapping. However, the hazards in such a situation are minimal in that the system is designed to shutdown any channels that show an over-current condition, thereby protecting the system hardware. All supply currents are monitored by the EPICS Slow Controls system.

The ALERT detector is positioned in the magnetic field of the CLAS12 solenoid. When the solenoid is energized to its full nominal current, the central field strength is 5 T and the field strength at upstream end of the detector is at the level of 1 kG. This field level presents a possible hazard to both personnel and to ALERT detectors (as well as the other detectors in located about the solenoid). As such no service work on the ALERT detector is to take place when the solenoid is energized.

During testing or repairs with the solenoid off, it is possible to access the front-end electronics racks and the upstream end of the ALERT detector. If there is need for the use of ladders or platforms, there are fall hazards that must be mitigated. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.10.8 Responsible Personnel

Individuals responsible for the ALERT ATOF system are (see Table 3.9):

Name	Dept.	Contact	Comments
Expert on call		757-329-4844	1st contact
W. Armstrong	ANL	warmstrong@anl.gov	2nd contact
R. Dupré	Orsay	raphael.dupre@ijclab.in2p3.fr	3rd contact

Table 3.9: Personnel responsible for the ALERT ATOF system.

3.11 Low Threshold Cherenkov Counter

The CLAS12 Low Threshold Cherenkov Counter (LTCC) is composed of four identical detectors installed in the S2, S3, S5, and S6 positions upstream of FTOF on the Forward Carriage. The detectors are filled with C_4F_{10} gas supplied by the Hall-B Gas system. The gas is cleaned, re-circulated, and maintained at a pressure between 1 – 4 inches of wc with gas flow controllers and bubble pressure relief units. Each sector contains 36 PMTs energized by a HV power supply. Each PMT produces two outputs, connected to VME electronics (FADCs, TDCs) on the Forward Carriage.

3.11.1 Hazards

There are three hazards identified with operation of the LTCC system.

- Electrical hazard when the HVPS is energized for the PMTs.
- Fall hazards from using man-lifts or ladders to access system elements during maintenance and testing operations.
- Gas pressure hazards when the detector is pressurized with C_4F_{10} , typically 1 – 4 inches of wc.

3.11.2 Mitigations

The HV hazard is mitigated by the maximum current settings on the power supply.

Harness training, man-lift training, ladder training, and fall protection training provides mitigation for the fall hazard during the detector maintenance. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

Detector pressure and vacuum is limited to a maximum of 4 inches of wc by the bubbler pressure relief units.

3.11.3 Responsible Personnel

Individuals responsible for the LTCC system are (see Table 3.10):

Name	Dept.	Phone	email	Comments
Expert on call		757-344-7174		1st contact
M. Ungaro	Hall B	x7808	ungaro@jlab.org	2nd contact
Y. Sharabian	Hall B	x5829	youris@jlab.org	3rd contact

Table 3.10: Personnel responsible for the CLAS12 LTCC system.

3.12 Forward Time-of-Flight System

The Forward Time-of-Flight System (FTOF) is mounted on the Forward Carriage in Hall B. In each of the six sectors of CLAS12, the FTOF system is comprised of three arrays of counters, named panel-1a, panel-1b, and panel-2. Each of the panels consists of a set of rectangular scintillation counters with a PMT on each end. The panel-1a and panel-1b arrays are located at forward angles (roughly 5° to 35°) and the panel-2 arrays are located at larger angles (roughly 35° to 45°). In each sector the panel-1a arrays contain 23 counters, the panel-1b arrays contain 62 counters, and the panel-2 arrays contain 5 counters.

3.12.1 Hazards

There are two hazards associated with the FTOF system related to i) the high voltage (HV) system used to energize the counter PMTs and ii) access to the counters during testing operations.

The HV power supplies for each FTOF sector are either CAEN 1527 or 4527 mainframes outfitted with negative polarity 24-channel A1535N modules. The typical settings for each channel are: $V = -2000$ V, $I = 350$ μ A. These supplies are located on the north and south sides of each level of the Forward Carriage behind each sector of counters. There are two hazards associated with the HV system when energized that must be mitigated. The first is the electrical hazard and the second is the potential damage to PMTs if a light leak is introduced in the counter wrapping material when the PMT is energized. All HV channel supply currents are monitored by the EPICS Slow Controls system.

The panel-1b and panel-1a counters are positioned between the LTCC and PCAL detectors on the Forward Carriage. Therefore they are not accessible for hands-on testing. However, the panel-2 counters are accessible for hands-on testing when the Forward Carriage is pulled back into its maintenance

position. The panel-2 counters in the S1, S2, S3, and S4 positions can then be accessed by manlift and the panel-2 counters in the S5 and S6 positions can be accessed by either manlift or ladders. When testing the panel-2 counters in such an operation there are fall hazards that must be mitigated.

3.12.2 Mitigations

The electrical hazard associated with the HV system would be to receive an electrical shock. However, the design of the HV system for the FTOF is such that the chance to receive an electrical shock is minimal. The electrical hazards are mitigated by the use of properly rated RG-59 cables that are terminated at the voltage divider end and the HV supply end. As well, the HV supplies are grounded to their electronics racks. The bigger issue would be damage to a PMT if improper contact with the counter surface were to occur that introduced a sizable light leak in the counter wrapping. However, the hazards in such a situation are minimal in that the HV system is designed to shutdown any channels that show an over-current condition, thereby protecting the system hardware.

Only authorized FTOF system personnel are allowed to work on the counters during hands-on testing when the Hall B configuration allows such work. For these individuals using ladders or manlifts, they are required to have all appropriate training including manlift and harness training, ladder training, and fall protection training as required by ePAS Permit to Work(s) (PTW). All work is carried out in conjunction with input from the FTOF Group Leader and the Hall B Work Coordinator.

3.12.3 Responsible Personnel

Individuals responsible for the FTOF system are (see Table 3.11):

Name	Dept.	Phone	email	Comments
Expert on call		757-344-7204		1st contact
D.S. Carman	Hall B	x5586	carman@jlab.org	2nd contact

Table 3.11: Personnel responsible for the CLAS12 FTOF system.

3.13 Electromagnetic Calorimeter

The CLAS12 Electromagnetic Calorimeter (EC) package includes both the legacy CLAS electromagnetic calorimeters (ECAL) and the new pre-shower calorimeter (PCAL) modules installed just upstream of ECAL. Both ECAL and PCAL are lead-scintillator sampling calorimeters consisting in total of 54 layers of 1-cm-thick scintillator strips and 52 layers of 2-mm-thick lead sheets. Photomultiplier tubes (PMTs) are used for light readout. The total number of readout channels is 2448. The nominal operational voltages for the ECAL and PCAL PMTs are 2200 V and 900 V, respectively.

3.13.1 Hazards

Hazards associated with this device are electrical shock or damage to the PMTs if the housing is opened with the HV on and the PMTs are exposed to room light. Access to some PMTs requires either ladders or manlift operations with potential fall hazards. Accessing signal cables below the floor gratings requires grating removal and poses a potential trip hazard over the open space.

3.13.2 Mitigations

Whenever any work has to be done on the calorimeter PMTs, the HV must be turned off. If work has to be done on the CAEN HV power supply, *i.e.* replacing HV cards, the HV mainframe must be powered off using the rear power switch to disable all circuits. Both extension and step ladders must be secured to structural beams or rails when accessing PMTs, and a harness must be worn for manlift operations. Open floor gratings must be surrounded on both sides by warning cones or yellow rope. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.13.3 Responsible Personnel

Individuals responsible for the EC system are (see Table 3.12):

Name	Dept.	Phone	email	Comments
Expert on call		757-810-1489		1st contact
C. Smith	UVA/JLab		lcsmith@jlab.org	2nd contact

Table 3.12: Personnel responsible for the CLAS12 EC system.

3.14 Central Time-of-Flight System

The Central Time-of-Flight (CTOF) system consists of 48 92-cm-long scintillation bars that form a hermetic barrel that is positioned within the 5 T superconducting solenoid magnet. Each counter is read out on both ends using PMTs through long light guides. The PMTs reside in inhomogeneous fringe fields from the magnet at levels as large as 1 kG and must be operated within specially designed magnetic shields with compensation coils.

3.14.1 Hazards

There are four hazards associated with the CTOF system related to i) the high voltage (HV) system used to energize the counter PMTs, ii) the low voltage (LV) system used to energize the compensation coils of the PMT magnetic shields, iii) the solenoid magnetic field, and iv) access to the counters during testing operations.

The HV power supply for the CTOF counters is either a CAEN 1527 or 4527 mainframe outfitted with negative polarity 24-channel A1535N modules. The typical settings for each channel are: $V = -2000$ V, $I = 350$ μ A. This supply is located on the south side of Level-1 of the Space Frame. There are two hazards associated with the HV system when energized that must be mitigated. The first is the electrical hazard and the second is the potential damage to PMTs if a light leak is introduced in the counter wrapping material when the PMT is energized.

The LV power supplies for the CTOF magnetic shield compensation coils are Wiener MPV8016I modules in an MPOD-mini crate located on the south side of Level-1 of the Space Frame. Each module has eight channels that can individually provide up to 50 W per channel with a maximum current of 5 A. There are two hazards associated with the LV system when energized that must be mitigated. The first is the electrical hazard and the second is the possible shield over-temperature condition if the supply current is set too high.

The CTOF detectors are positioned in the magnetic field of the CLAS12 solenoid. When the solenoid is energized to its full nominal current, the central field strength is 5 T and the field strength at the location of the PMTs is at the level of 1 kG. This field level presents a possible hazard to both personnel and to the CTOF detectors (as well as the other detectors in located about the solenoid). As such no service work on the CTOF counters is to take place when the solenoid is energized.

During testing or repairs with the solenoid off, it is possible to access the counter light guides, PMTs, and magnetic shields through the use of ladders and platforms, and possibly via manlifts. When testing the CTOF counters in such an operation there are fall hazards that must be mitigated.

3.14.2 Mitigations

The electrical hazard associated with the HV system would be to receive an electrical shock. However, the design of the HV system for the CTOF is such that the chance to receive an electrical shock is minimal. The electrical hazards are mitigated by the use of properly rated RG-59 cables that are terminated at the voltage divider end and the HV supply end. As well, the HV supplies are grounded to their electronics racks. The bigger issue would be damage to a PMT if improper contact with the counter surface were to occur that introduced a sizable light leak in the counter wrapping. However, the hazards in such a situation are minimal in that the HV system is designed to shutdown any channels that show an over-current condition, thereby protecting the system hardware. All HV channel supply currents are monitored by the EPICS Slow Controls system.

The electrical hazard associated with the LV system would be to receive an electrical shock. However, the design of the LV system for the CTOF is such that the chance to receive an electrical shock is minimal. The electrical hazards are mitigated by the use of properly rated power cables that are terminated at the shield end and the LV supply end. As well, the LV supplies are grounded to their electronics racks. Another issue with the power supplies is that the higher the current setting, the higher the temperature of the shields. The shields are outfitted with a thermistor system to monitor their temperature through EPICS. This system is connected to an interlock on the supply to kill the power if the shield temperature reaches $\sim 90^{\circ}\text{F}$. The nominal operating currents for the shields are in the range from 0.5 A to 1.0 A where the shield temperature remains at room temperature.

The magnetic field hazard associated with the CTOF system must be mitigated for both personnel and detectors. No service work is to be done on the CTOF counters when the solenoid is energized. This mitigates any hazards associated with personnel working in a strong magnetic field environment. All CTOF electronics and power supplies are located outside of the 5 G solenoid field boundary marked with labels on the floor of level-1 of the Space Frame as well as with a roped off boundary. Work outside of this boundary is allowed whenever hall access is possible.

Only authorized CTOF system personnel are allowed to work on the counters during hands-on testing when the Hall B configuration allows for such work. For these individuals using ladders, platforms, or manlifts, they are required to have all appropriate training including manlift and harness training, ladder training, and fall protection training where necessary. All work is carried out in conjunction with input from the CTOF Group Leader and the Hall B Work Coordinator. Also, after any sort of maintenance work is done on the CTOF, the area must be inspected and all ferromagnetic tools and equipment must be removed before the solenoid field is ramped up again. Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.14.3 Responsible Personnel

Individuals responsible for CTOF the system are (see Table 3.13):

Name	Dept.	Phone	email	Comments
Expert on call		757-344-7204		1st contact
D.S. Carman	Hall B	x5586	carman@jlab.org	2nd contact

Table 3.13: Personnel responsible for the CLAS12 CTOF system.

3.15 Central Neutron Detector

The Central Neutron Detector (CND) is the outer-most detector of the CLAS12 Central Detector. The CND is a barrel of plastic scintillator bars of trapezoidal shape, all with their long sides parallel to the beam direction.

The light emitted by the scintillators of the CND is read out only at the upstream end of each bar with a Hamamatsu R10533 photomultiplier placed in the low-field region of the solenoid and connected to the bar by a ~ 1.5 -m-long bent light guide; the downstream end of each bar is connected via a “U-turn” light guide to the neighboring paddle. In this way, the light emitted at the downstream end of each scintillator is fed through its neighboring paddle and read out by the PMT connected to its end. Each PMT is encased in a cylindrical magnetic shield made up by a 1-mm-thick layer of mu-metal and a 5-mm-thick layer of mild steel.

The CND is composed of 48 azimuthal segments and 3 layers in the radial direction, for a total of 144 scintillator bars, 144 PMTs, 72 U-turn light guides, and 144 bent light guides.

In order to operate the PMTs, high voltages (typically in the range of 1500 V) are provided by a multi-channel CAEN SY527 power supply. The signal of each PMT is sent to an active splitter. The three splitter modules used for the CND were originally developed by IPN Orsay for the G0 experiment (Hall C, Jefferson Lab). Each module is an active 64-channel splitter with unity gain so there is no loss of amplitude. The 64 SMA inputs are placed in the back panel. In the front panel there are 8 8-channel output connectors (DMCH) for the timing signals and 4 16-channel output connectors (FASTBUS) for the charge signals. The charge signal is sent from the splitter to the flash-ADC (250 VXS, 16 channels/board, made and owned by JLab). The timing signal from the splitter is sent to a constant fraction discriminator (CFD) GAN'ELEC FCC8, developed for the TAPS Collaboration. The module is an 8-channel CAMAC unit with LEMO 00 input connectors and 2x 8-pin output connectors in differential ELC. The threshold can be set for each channel individually and no time-walk adjustment is required for the module. The discriminated timing signal then goes to the TDC (CAEN VX1290A, 32 channels/board, 25 ps/channel resolution). In total, the read-out of the CND includes 3 splitter modules, 19 CFD modules, 5 TDC boards, and 8 ADC boards.

3.15.1 Hazards

3.15.1.1 Electrical Hazard

The electrical hazard to personnel can come from the high voltage that powers the PMTs, which need about 1500 V to function.

3.15.1.2 Magnetic Field Hazard

The strong magnetic field of the solenoid (5 T) represents a hazard for all detectors of the CND.

3.15.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.15.2.1 Electrical Hazard Mitigations

The maximum current provided by the HV distribution boards is quite low (3 mA). All mechanical structures are properly grounded. The HV boards must not be accessed during operation; during maintenance work, performed by trained personnel, the HV is turned off, cables are disconnected from the power supply and the power supply is turned off.

3.15.2.2 Magnetic Field Hazard Mitigations

Whenever any work has to be done on the CND, the magnetic field of the solenoid must be turned off. After any sort of maintenance work is done on the CND, the area must be inspected and all ferromagnetic tools and equipment must be removed before the field is ramped up again. Also, before the field can be turned on the PMT housings and magnetic shields should be thoroughly inspected to make sure that they are properly secured and that there are no loose parts.

3.15.3 Responsible Personnel

Individuals responsible for the CND system are (see Table 3.14):

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
S. Niccolai	IPN Orsay	+33 6 24 81 67 78	silvia@jlab.org	2nd contact
D. Sokhan	Glasgow	+ 44 7949 175725	daria@jlab.org	3rd contact
D.S. Carman	Hall B	x5586	carman@jlab.org	JLab contact

Table 3.14: Personnel responsible for the CLAS12 CND system.

3.16 Ring Imaging Cherenkov Counter

The Ring Imaging Cherenkov detector (RICH) is designed to improve the CLAS12 particle identification in the momentum range from 3 to 8 GeV. RICH modules are installed in the S1 and S4 positions upstream of FTOF on the Forward Carriage. The Ring Imaging Cherenkov Counter incorporates:

1. Aerogel radiator. Aerogel is very light material, non-toxic, and non-flammable but hygroscopic.
2. Focusing mirror system. Mirrors reduce the detection area instrumented by the photo-detectors to $\sim 1 \text{ m}^2$.
3. Photo-detector. The photo-detector includes 391 Hamamatsu multi-anode photomultipliers (MAPMTs). Each MAPMT has 64 pixels, so the detector has 25024 channels.
4. High Voltage. High voltage is supplied to each MAPMT. The MAPMT high voltage is less than 1100 V and the divider current is $225 \mu\text{A}$. The power consumption for all MAPMTs is $\sim 100 \text{ W}$.
5. Front-end electronics. The front-end electronics consist of three types of boards: adapter board, ASIC board, and FPGA board. There are two types of the front-end boards: 3 MAPMTs tiles and 2 MAPMTs tiles. The photo-matrix has 23 boards with two MAPMTs and 115 boards with three MAPMTs. In total the RICH has 138 tiles of each type.
6. Low voltage system. The typical current draw is 0.8 A for the FPGA and ASIC boards together (3 MAROC version) from a +5 V source. The power used for the 2 MAROC ASIC setup will be slightly less. The total power consumption is no more than 500 W.

7. Cooling system. The RICH detector electronics are sealed inside the detector. The heat generated by the HV and LV circuits must be removed in order to prevent damage to the electronics package and the adjacent FTOF panel. Air cooling was determined to be the viable method.
8. The Nitrogen Purge System. In order to preserve the aerogel optical performance, the RICH box environment must be kept dry by flushing with nitrogen gas. The nitrogen purge system supplies the amount of gas necessary to fill the box (about 5 m³) and to compensate for the gas leakage. A complete refill of the volume each day is expected under normal operating conditions. A slight over-pressure of 0.5 mbar prevents contamination from the outside air.

3.16.1 Hazards

Hazards associated with the RICH detector:

1. Electrical shock from touching exposed wires or damage to the MAPMTs if the detector enclosure is opened with HV on.
2. Heat buildup inside the RICH enclosure if the cooling system is not running. This may cause damage to the experimental equipment.
3. The degradation of aerogel properties due to uncontrolled humidity in the experimental hall.

3.16.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

1. Whenever any work has to be done on the RICH detector, whether it will be opened or not, the HV and LV must be turned off. The cooling system has to be turned off if the enclosure is opened for maintenance. The door interlock will turn off the HV to prevent touching exposed HV cables or damage of the MAPMTs in case the door is opened accidentally.

2. The air cooling and nitrogen purge systems monitor key detector parameters. If the monitored signals are outside of pre-programmed limits, the air cooling system shuts off voltage to the electronics.

The signals monitored for air cooling include:

- Air flow
- Detector internal temperature
- Pressure inside air tank
- Air compressor power status

High capacity air compressors supply clean dry air at room temperature to cool the electronics package inside the detector. The plan is to have two compressors in parallel charging a 1000 l capacity air tank. Air pressure is reduced to supply manual valve flow meters, one per detector. In the case of a power outage, the air tank should contain sufficient air to remove the latent heat of the electronics package.

Powering up the electronics package inside the RICH without cooling may result in severe damage. Interlocking the RICH HV and LV power supply operation to proper cooling circuit operation eliminates this hazard. The interlocks perform two functions in the case of a cooling system fault:

- Turn off power to the electronics package,
- Prevent energizing the electronics package.

There are 3 cooling circuit interlocks:

- Air compressor operation: minimum one compressor operating,
- Minimum air pressure in tank,
- Minimum cooling air flow.

All three interlocks must be true in order for the electronics package to have power.

3. The aerogel used in the RICH detector requires very dry air in order to perform properly. The nitrogen purge gas system provides gas at low humidity levels.

The signals monitored for the nitrogen purge system include:

- Nitrogen flow,
- Detector internal humidity.

If the monitored signals are outside of pre-programmed limits, the nitrogen purge system sets off an alarm.

3.16.3 Responsible Personnel

Individuals responsible for the RICH detector are (see Table 3.15):

Name	Dept.	Phone	email	Comments
Expert on call	Hall B	757-344-3235		1st contact
V. Kubarovsky	Hall B	x5649	vpk@jlab.org	2nd contact
M. Mirazita	INFN		mirazita@jlab.org	3rd contact
M. Contalbrigo	INFN		mcontalb@jlab.org	4th contact
A. Kim	UConn		kenjo@jlab.org	5th contact

Table 3.15: Personnel responsible for the CLAS12 RICH detector.

3.17 Forward Tagger System

The Forward Tagger system consists of three subsystems: an electromagnetic calorimeter (FT-Cal), a plastic scintillator hodoscope (FT-Hodo), and a MicroMegas-based tracker (FT-Trk). In the following, details are reported for each of the three subcomponents.

3.17.1 Forward Tagger Calorimeter

The Forward Tagger calorimeter (FT-Cal) consists of 332 lead-tungstate (PbWO_4) crystals with avalanche photodiode (APD) readout and amplifiers enclosed inside a temperature-controlled enclosure. The crystals are arranged in a circular matrix positioned around the beamline. The system is located in proximity of magnets, in an area where the fringe field is of the order of a few hundred gauss. In order to operate the calorimeter, high voltage and low voltage are supplied to each channel. The high voltage is < 420 V and < 50 μA . The required low voltage is ± 5 V for the preamplifier boards and 12 V for the Light Monitoring System. Constant temperature

inside the enclosure is kept by running a coolant through the copper pipes that are integrated into the enclosure using a laboratory chiller. The cooling system should provide temperature stability at the level of 1°C. To avoid moisture build-up in the calorimeter enclosure, a steady flow of nitrogen gas is maintained and the temperature and humidity in the calorimeter enclosure are monitored with sensors interfaced to the CLAS12 Slow Controls system.

3.17.1.1 Hazards

Hazards to personnel associated with this device are high voltage, which is supplied to the photosensors, and low voltage, which powers the calorimeter preamplifiers and Light Monitoring System. Hazards to the detector include cooling fluid leaks or condensation in the photosensors and preamplifier region, over-voltage to the photosensors, preamplifiers, or Light Monitoring System that could damage the related subsystem, and absence of cooling or cooling failure when low voltage is applied to the preamplifiers, which could lead to overheating of the preamplifiers themselves. To account for the presence of fringe magnetic fields from the CLAS12 magnets in the system location, no ferric materials are employed in the detector: a hazard may nevertheless arise during maintenance operations in case metallic tools are used and for people with cardiac pacemakers, other electrical medical devices, or metallic implants.

3.17.1.2 Mitigations

Mitigation of risks associated with FT-Cal operations are achieved in the following ways and must be covered by ePAS Permit to Work(s) (PTW).

- Electrical shock: there is only a low level hazard for personnel related to the limited voltage/current range in use. Nevertheless, during maintenance periods, HV and LV power needs to be off before working on the calorimeter, cables disconnected, and lock and tags supplied;
- to avoid any damage to photosensors and preamplifiers, hardware interlocks prevent any incorrect HV/LV settings;
- to avoid any damage to preamplifiers due to a possible coolant leakage, all cooling lines will be tested at high pressure and chiller parameters and temperatures monitored; hardware interlocks switch off the chiller in case of monitored parameters outside allowed range;

- over-temperature causing damage to the preamplifiers will be avoided by continuously monitoring the status of the cooling and calorimeter temperature; interlocks will trigger HV/LV turn-off if the temperature exceeds the set values.

3.17.1.3 Electrical Hazard Mitigation (Personnel)

High Voltage: high voltage up to 420 V is supplied to the photosensors (Hamamatsu S8664-1010 Large Area Avalanche Photodiode or LAAPD). Mitigation: a very low current limit ($50\ \mu\text{A}$) is set. All mechanical structures are properly grounded. HV distribution boards on the detector cannot be accessed during operation; during maintenance work, performed by trained personnel, the HV cables are disconnected from the power supply and the power supply locked and tagged.

Low Voltage: In order to power up the LAAPD preamplifier and Light Monitoring System, we use low voltage at $\pm 5\text{ V}$ and 12 V , respectively, with a maximum current of 4 A . Mitigation: voltage is low enough not to be a danger to personnel. All mechanical structures are properly grounded. All cables and connectors are certified for this rating. LV distribution boards on the detector cannot be accessed during operation; during maintenance work, performed by trained personnel, the LV cables are disconnected from the power supply and the power supply locked and tagged.

3.17.1.4 Electrical Hazard Mitigation (Equipment)

High Voltage: if high voltage is applied when the low voltage is turned off, the LAAPD preamplifiers may be damaged. Mitigation: the HV operation is interlocked to the LV settings, so that HV cannot be supplied if LV is off.

Over-voltage: applying HV and LV above certain values can damage the photosensors and preamplifiers. Mitigation: both HV and LV are monitored via the EPICS Slow Controls system; reading above predefined limits will automatically trigger the supplied voltage to be turned off.

3.17.1.5 Other Hazard Mitigation

Cooling fluid: leaks of the cooling fluid may cause damage to the calorimeter preamplifiers or nearby electronic components. Mitigations: during the design phase the cooling circuit path was chosen in order to minimize risks and, after the assembly, was tested at high pressure to verify the absence of

leaks. During operation the temperature, level, and pressure of the liquid at the chiller output, as well as the temperatures of the calorimeter inlet and outlet lines, are monitored continuously via the EPICS Slow Controls system: any significant temperature variation (more than 1°C) or sudden pressure variation must be investigated. The chiller operation is interlocked to these parameters so that variation outside appropriate limits will trigger the chiller being turned off.

Moisture: since the calorimeter is operated at 0°C, moisture may build up in the system enclosure if the nitrogen gas flow is interrupted. Mitigation: the humidity inside the calorimeter enclosure is monitored via sensors; the operation of the LV and HV supplies are interlocked to the humidity readings so that, if the humidity exceeds a predefined threshold, both supplies will be automatically turned off.

Over-temperature: absence of cooling or cooling failure when LV is supplied to the preamplifiers may cause over-heating of the preamplifiers and other calorimeter components. Mitigation: cooling status and temperature inside the calorimeter enclosure are monitored and interlocked to the LV operation so that when the cooling is not in operation or temperatures exceed predefined limits, the LV is turned off.

Magnetic field: a hazard for personnel and equipment may arise if maintenance operations are performed while magnets are energized. Mitigation: the detector area is not accessible during regular CLAS12 operation; accessing the detector area implies the displacement of other CLAS12 subsystems that requires the magnet to be turned off. Energized magnets are noted by red flashing beacons.

3.17.1.6 Responsible Personnel

Individuals responsible for the FT-Cal system are (see Table 3.16):

Name	Dept.	Phone	email	Comments
Expert on call		757-344-1848		1st contact
R. De Vita	Hall B	x5701	devita@jlab.org	2nd contact
M. Battaglieri	INFN		battaglieri@jlab.org	3rd contact

Table 3.16: Personnel responsible for the CLAS12 FT-Cal system.

3.17.2 Forward Tagger Hodoscope

The Forward Tagger Hodoscope (FT-Hodo) consists of 232 plastic scintillator tiles (Eljen EJ 204) coupled to 6-m-long optical fibers with SiPM readout, preamplifier, and mezzanine and control electronic PCBs enclosed in an electronics crate. The system is located in the proximity of magnets, in an area where the fringe field is of the order of a few hundred gauss.

The FT-Hodo Light Monitoring System consists of a 420 nm (violet) peaked LED (Thorlabs M420F2), LED driver (LED D1B T-Cube), ten optical fibers, and eight cylindrical diffusers (Medilight). The LED and driver are located in the electronics rack and the optical diffusers are located in the plastic scintillator enclosure, four in each layer.

3.17.2.1 Hazards

Hazards are electric shock if the electronics enclosure is opened without switching off the HV and LV, or exposure to non-ionizing UV radiation if the UV LED safety mitigations are not adhered to.

The LED is capable of producing high intensity UV light, which poses an eye and skin hazard.

The SiPMs can be damaged if they are subjected to over-voltage or over-current and are sensitive to electrostatics.

To account for the presence of fringe magnetic fields from the CLAS12 magnets in the system location, no ferric materials are employed in the detector: a hazard may nevertheless arise during maintenance operations in case metallic tools are used and for people with cardiac pacemakers, other electrical medical devices, or metallic implants.

3.17.2.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

Whenever any work has to be done on the Hodoscope, whether it will be opened or not, HV and LV cables are disconnected from the power supply and the power supply locked and tagged.

Junctions for the LED light are: LED to optical fiber (SMA connector), optical fiber into splitter box, splitter box to 11 output optical fibers, fibers to SiPM, and fibers illuminating the inside of the hodoscope. All of these junctions are completely sealed and light-tight. The fiber must not be disconnected from the LED source while the LED is operating. The splitter box or the hodoscope enclosure must not be opened while the LED is operating. The fibers should never be disconnected from the SiPMs while the LED is operating.

The Light Monitoring System must not be turned on or left on when the electronics enclosure or plastic scintillator enclosure are opened. The LED should not be looked at directly - eye protection must be worn. Warning labels are applied to the LED enclosure and plastic scintillator enclosure. During maintenance work, performed by trained personnel, the Light Monitoring System will be disconnected from power and locked and tagged.

A magnetic field hazard for personnel and equipment may arise if maintenance operations are performed while magnets are energized. Mitigation: the detector area is not accessible during regular CLAS12 operation; accessing the detector area implies the displacement of other CLAS12 subsystem that require the magnet to be turned off. Energized magnets are noted by red flashing beacons.

3.17.2.3 Responsible Personnel

Individuals responsible for the FT-Hodo system are (see Table 3.17):

Name	University	email	Comments
N. Zachariou	York	<code>nick.zachariou@york.ac.uk</code>	1st contact (general)
D. Watts	York	<code>daniel.watts@york.ac.uk</code>	2nd contact (general)
D. Sokhan	Glasgow	<code>daria@jlab.org</code>	3rd contact (flasher)

Table 3.17: Personnel responsible for the CLAS12 FT-Hodo system.

3.17.3 Forward Tagger Tracker

The Forward Tagger Tracker is composed of two double-sided Micromegas double-stage gaseous detectors. The system is located in the proximity of magnets, in an area where the fringe field is of the order of a few hundred gauss. The detectors are based on the resistive Micromegas technology that is also employed in the CLAS12 Central Micromegas tracker. Each detector consists of two planes with strips oriented along the x and y axes, respectively, separated by 10 mm. Each plane has 768 strips with 560 μm pitch. The FT tracker covers the polar angle region from 2.5° to 4.5° from the target. The fill gas is a mixture of 80% argon, 10% CF_4 , and 10% isobutane. Even though isobutane is a flammable gas, the amount of gas in use at any given time is well within the range of a class-0 gaseous device.

The FT-Tracker is powered by high voltages up to 2000 V. The current limit for all three HV is extremely low (< 1 mA). The detectors are read out through 1.5-m-long, low-capacitance flex cables by Front-End Units (FEU). These electronic cards contain the customized DREAM ASICs in order to sample the detector signal and a Flash-ADC to digitize it and send it to the network. The FEUs are placed inside customized crates, installed on the outer case of the FT calorimeter. They are powered through low voltage, and kept within a 40°C to 60°C temperature range using a simple set of fans and tubing.

All hazards and mitigation options for the FT tracker are the same as for the CLAS12 Central Micromegas tracker (FMT and BMT). Even though the shapes of the detectors vary, they are almost identical in principle.

3.17.4 Hazards

Hazards to personnel include the use of flammable gas, high voltage, and the low voltage that powers the readout electronics. Hazards to the detector include mechanical damage, gas leaks, and gas over-pressure. Hazards concerning the Front-End Units include: wrong LV settings that could damage the FEUs and absence of cooling or cooling failure that could overheat the cards. To account for the presence of fringe magnetic fields from the CLAS12 magnets in the system location, no ferric materials are employed in the detector: a hazard may nevertheless arise during maintenance operations in case metallic tools are used and for people with cardiac pacemakers, other electrical medical devices, or metallic implants.

3.17.5 Mitigations

Mitigation of risks associated with then FT-Trk operations are achieved in the following ways and must be covered by ePAS Permit to Work(s) (PTW).

- the limited amount of flammable gas (10% isobutane over the whole gas in the detector) makes this a class-0 gas system. Nevertheless, the supply and exhaust are located outside Hall B, all flows monitored, and hardware interlocks are used to avoid leaks and over-pressure;
- the low voltage/current range represents a low level electrical hazard for personnel. Nevertheless, during maintenance the HV and LV will be powered-off, cables disconnected, and locks and tags supplied;
- Interlocks on the gas supply will mitigate possible leaks and over-pressure conditions;
- continuous LV monitoring in conjunction with hardware interlocks will reduce possible issues with wrong settings. FT-Trk temperature monitoring will provide a fast LV turn-off in case of cooling failures or over-temperature conditions.

3.17.5.1 Fire Hazard Mitigation (Equipment and Personnel)

Use of flammable gas: the FT-Trk detectors use 10% isobutane, which is flammable. However the amount of isobutane in the system is very limited. The gas supply and exhaust are located outside Hall B. The total combustion energy is equivalent to less than 4 g of hydrogen, which makes it a class-0 gas system (class-1 starts at 600 g).

General fire hazards and procedures for dealing with these are covered by JLab emergency management procedures. The JLab Fire Protection Manager (Tim Minga) can be contacted at Office: 757-269-7310, Cell: 757-371-1687.

3.17.5.2 Electrical Hazard Mitigation (Personnel)

High Voltage: high voltages up to 2000 V are used routinely for the detectors. Mitigation: very low current limit (10 μ A) is set. All mechanical structures are properly grounded.

Low Voltage: In order to power up the front-end electronics, we use low voltage at 6 V with 15 A per crate. Mitigation: voltage is low enough not to be a danger to personnel. All mechanical structures are properly grounded. All cables and connectors are certified for this rating.

3.17.5.3 Other Hazard Mitigation

Detectors: gas over-pressure, gas leaks, mechanical damage. Mitigation: gas control system with over-pressure and leak limit detection by flow meter (limit = 0.4 l/hr). The FT tracker detectors can be dismounted and repaired in case of accidental damage to the drift electrode. Since they are tightly stacked, only one such electrode is exposed and at risk, the rest of the stack is protected by the first detector.

Electronics: wrong LV settings, absence of cooling or cooling failure. Mitigation: Slow Controls read-back of LV setting before turning on the front-end electronics. Cooling is also checked by the Slow Controls system, and is interlocked so that the electronics cannot be turned on when the cooling is off. Also, temperature sensors are present on the front-end cards and are directly interlocked so that if the temperature goes beyond a predefined threshold, the cards are shut-down automatically.

Magnetic field: a hazard for personnel and equipment may arise if maintenance operations are performed while magnets are energized. Mitigation: the detector area is not accessible during regular CLAS12 operation; accessing the detector area implies the displacement of other CLAS12 subsystems that require the magnet to be turned off. Energized magnets are noted by red flashing beacons.

3.17.5.4 Responsible Personnel

Individuals responsible for the FT-Trk system are (see Table 3.18):

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
R. Paremuzyan	Hall B	x7950	rafopar@jlab.org	2nd contact
Y. Gotra	Hall B	x5571	gotra@jlab.org	3rd contact
R. De Vita	Hall B	x5701	devita@jlab.org	4th contact

Table 3.18: Personnel responsible for the CLAS12 FT-Trk system.

3.18 Backward Angle Neutron Detector

The Backward Angle Neutron Detector (BAND) is placed at the top of the CVT cart upstream of the CLAS12 target. It consists of 116 scintillator bars, arranged in 18 rows and 5 layers. Four bars are missing in the bottom of the detector due to obstruction. The bars have a cross section of $7.2 \times 7.2 \text{ cm}^2$ and they are 164 and 202 cm long in the upper region of BAND. In the bottom region the bars are divided into two shorter bars 51 cm to have a hole for the beamline and target installation. All bars are read-out on both ends by PMTs (Hamamatsu R7724 and ET9214) giving a total of 232 active channels.

In front of the first active layer of BAND, a veto layer is installed with 24 bars read-out only on one side. Therefore, the total number of channels for BAND is 256. The PMTs are placed in the fridge field region of the solenoid, and due to this they are encased in a cylindrical shielding made up by a 2-mm-thick layer of mu-metal.

In order to operate the PMTs, high voltages (typically in the range of 1500 V) are provided by a multi-channel CAEN SYS4527 mainframe with 11 A15350 cards (24 channel each). The signal of each PMT is sent to an 50/50 splitter. From the splitter one signal is sent to flash-ADCs (250 VXS, 16 channels/board), while the other signal is sent to discriminators used by HPS (16 channels/board). The discriminated time signal then goes to a TDC (CAEN VX1190A, 128 channels/board, 100 ps/channel resolution). The read-out system is installed in the racks on the south side of the Space Frame on the target level. In total, the system consists of 16 flash-ADCs in one VXS crate, 16 discriminators and a TDC in a VME crate, and 16 splitters. Furthermore, a signal distribution card for the flash-ADCs and trigger interface boards is installed in the crates.

The laser calibration system consists of a Photonics STV-01E-140 picosecond pulse laser with a wavelength of 355 nm, several splitters, reference photodiode, and a fiber distribution system. All of these components are in a sealed, light-tight box. The output of the laser is about $1 \mu\text{J}$ per pulse at 0.3 ns width (FWHM) that is attenuated and distributed to all fiber outputs that each have an output of about 200 pJ. The fibers are connected via a patch panel to each scintillator bar.

3.18.1 Hazards

3.18.1.1 Electrical Hazard

The electrical hazard to personnel can come from the high voltage that powers the PMTs, which need about 1500 V to function.

3.18.1.2 Fall Hazard

Fall hazard from maintenance and testing operations of BAND that require the use of ladders to access system elements in up to 1.5 m.

3.18.1.3 Magnetic Field Hazard

BAND is placed in the fringe field of the solenoid (50 - 100 gauss). A hazard may arise during maintenance operations in case metallic tools are used and for people with cardiac pacemakers, other electrical medical devices, or metallic implants.

3.18.1.4 Laser Hazard

The laser hazard comes from the laser calibration system and its connection with fibers to the scintillator bars when work is done on BAND. The system itself is closed, light-tight and the output on each fiber is ≈ 200 pJ. This intensity is comparable to that of a LED, however, the 355 nm wavelength could be damaging to the human eye since it is invisible to the eye and the natural eye reflex will not be triggered.

3.18.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.18.2.1 Electrical Hazard Mitigations

The electrical hazard associated with the HV system is mitigated by the use of properly rated RG-59 cables that are terminated at the voltage dividers and the HV supplies. The HV supplies are grounded to their electronics racks as well. The maximum current provided by the HV distribution boards is quite low (< 1 mA). The HV system is designed to shutdown any channels that show an over-current condition. The HV boards must not be accessed

during operation; during maintenance work, performed by trained personnel, the HV is turned off, and the power supply is switched off by the power switch on the back of the crate.

3.18.2.2 Fall Hazard Mitigations

Fall hazard mitigation consists of appropriate training like fall protection training. For individuals using ladders, they are required to take the appropriate ladder training.

3.18.2.3 Magnetic Field Hazard Mitigations

The magnetic field hazard must be mitigated for both personnel and detector components. Normally no servicing work is to be done with the BAND detector when the solenoid is energized. This mitigates any hazard associated with personnel working in a strong magnetic field environment. After all maintenance work is done on BAND, the area must be inspected and all ferromagnetic tools must be removed before the field of the solenoid is ramped up again. This mitigates the hazard for the detector.

3.18.2.4 Laser Hazard Mitigations

The laser calibration system is a closed system with fibers connected to the scintillator bars via a patch panel. All of these connections are light-tight. Furthermore, no fiber must be disconnected from the system while it is operating. While the laser intensity in each fiber is very small (≈ 200 pJ), and comparable to that of a LED, the 355 nm wavelength could be damaging to the human eye. Therefore, one should not look directly at the fiber output - eye protection must be worn.

Warning labels are applied on the enclosure of the laser system, the patch panel, and detector frame. The box containing the laser system is interlocked such that if the box is open the power is off. If the system is not in use by trained personnel, it will be powered off. During maintenance work on the laser system, performed by trained personnel, the laser system is turned off, disconnected from the power supply, and locked and tagged. The procedures for maintenance work on the laser system can be found in the LOP.

3.18.3 Responsible Personnel

Individuals responsible for the BAND system are (see Table 3.19):

Name	Dept.	Phone	email	Comments
Expert on call		757-310-7198		1st contact
F. Hauenstein	Hall B	757-746-3395	hauenst@jlab.org	2nd Contact
O. Hen	MIT		hen@mit.edu	3rd Contact
L. Weinstein	ODU		weinstein@jlab.org	4th contact

Table 3.19: Personnel responsible for the CLAS12 BAND Detector.

3.19 Superconducting Solenoid Magnet

The CLAS12 solenoid magnet provides the magnetic field for the tracking of charged particles and suppression of low energy electron background. It hosts several detector packages including the ALERT detector, the Central Time-of-Flight, and the Central Neutron Detector. They all are located in the 780-mm-diameter warm bore. The solenoid has four main coils and one shield coil. The solenoid produces a magnetic field of 5 T when powered at 2416 A. The magnet has an overall inductance of 5.89 H and stored energy of 17.2 MJ.

3.19.1 Hazards

The hazards of the solenoid magnet include the following:

- Electrical hazard
- Cryogenic hazard
- Vacuum hazard
- Magnetic field
- Stored energy

3.19.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.19.2.1 Electrical Hazard

The power supply for the solenoid operates with input voltages of 120 VAC and 480 VAC and is interlocked to a current limit of 2450 A. Maintenance and servicing of the power supply can only be conducted by “Qualified Electrical Workers”. Additional information can be found in the ePAS and procedures for the Hall B solenoid magnet. During normal operation, connections at the power supply are made inside the cabinet that has interlocked doors. Insulated cables carrying current to the magnet are routed with cable trays with all exposed leads and terminations covered by non-conductive or expanded metal enclosures. During a fast dump or quench, high voltage spikes may be induced on current leads and voltage taps. The leads from the voltage tap wires connect to the control system wiring through current limiting resistors to reduce any current-voltage combination to within the class-1 Electrical Classification of the ES&H Manual.

3.19.2.2 Cryogenic Hazard

Nitrogen and helium are two types of cryogenics used to keep the coils superconducting. The total volume of liquid helium and liquid nitrogen in Hall B is less than 900 liters and 130 liters, respectively. Proper insulation is installed on all piping accessible to personnel. In the event of a quench or loss of insulating vacuum event, relief valves on the helium and nitrogen circuits vent generated gas to the hall. In case of such an event, Hall B remains ODH-0. In case of a power outage, the hall ODH rating would go up to ODH-2 after five hours. Appropriate ODH signs are posted at all entrances to the hall and an oxygen monitoring system is installed in the hall and operational.

3.19.2.3 Vacuum Hazard

The purpose of the vacuum system is to provide 10^{-5} Torr or better thermal insulating vacuum to four superconducting coils and one cryogenic distribution box. After liquid helium is introduced into the coils, a Loss of Vacuum (LOV) event with a full air inrush can lead to very high heat transfer to the helium and nitrogen circuits with a resulting phase change in the liquid helium and nitrogen and potential high pressure expulsion from the system. In the event of an LOV event, relief valves on the helium and nitrogen circuits vent generated gas to the hall.

3.19.2.4 Magnetic Field

When powered up to 2416 A, the solenoid can generate up to 5 T field in the center of the magnet and up to 1 kG in the zones that extend beyond the magnet boundaries. The 5 G boundary restricting access by personnel with surgical implants and bioelectric devices, the 200 G crane boundary, and the 600 G whole body boundary were found and recorded during the commissioning of the magnet. These contours are be marked up and appropriate signage posted. Strong magnetic fields will attract loose ferromagnetic objects, possibly injuring body parts or striking fragile components. Prior to energizing the magnet, a sweep of the surrounding area must be performed for any loose magnetic objects. All personnel entering the 600 G area will also be trained to remove ferromagnetic objects from themselves. To prevent personnel with surgical implants and bioelectric devices from entering the 5 G boundary, lighted warning signs are placed at the doors of the hall when the solenoid is energized, and flashing red beacons and personnel barricades are installed at the actual 5 G contour.

3.19.2.5 Stored Energy

At 2416 A, the total energy stored in the magnet is about 17.2 MJ. Upon sudden loss of hall electrical power or quench or LOV, the energy is dumped into a dump resistor.

3.19.3 Responsible Personnel

Individuals responsible for the CLAS12 solenoid system are (see Table 3.20):

Name	Dept.	Phone	email	Comments
Engineering on call		757-748-5048	—	1st contact
B. Miller	Hall B	x7867	miller@jlab.org	2nd contact
K. Bruhwel	Hall B	x7868	bruhwel@jlab.org	3rd contact

Table 3.20: Personnel responsible for the CLAS12 solenoid magnet system.

3.20 Superconducting Toroidal Magnet

The CLAS12 torus magnet provides the magnetic field for the tracking of forward-going charged particles and hosts several detector packages, including the Drift Chambers and Forward Tagger. It consists of six coils housed in an aluminum case that is approximately $2 \times 4 \times 0.05 \text{ m}^3$. The six coils produce a peak magnetic field of 3.58 T when powered at 3770 A. The magnet has an overall inductance of 2.0 H, stored energy of 14.2 MJ, and is roughly 8 m in diameter. Each coil is conductively cooled by supercritical helium gas supplied at 4.6 K from cooling tubes located on the coil inner diameter.

3.20.1 Hazards

The hazards of the torus magnet include the following:

- Electrical hazard
- Cryogenic hazard
- Vacuum hazard
- Magnetic field
- Stored energy

3.20.2 Mitigations

Any work on this system must be covered by ePAS Permit to Work(s) (PTW).

3.20.2.1 Electrical Hazard

The power supply for the torus operates with input voltages of 120 VAC and 480 VAC and is interlocked to a current limit of 3800 A. Maintenance and servicing of the power supply can only be conducted by “Qualified Electrical Workers”. Additional information can be found in the ePAS and procedure for the Hall B toroidal magnet. During normal operation, connections at the power supply are made inside the cabinet that has interlocked doors. Insulated cables carrying current to the magnet are routed within cable trays with all exposed leads and terminations covered by non-conductive or expanded metal enclosures. During a fast dump or quench, high voltage spikes may be

induced on current leads and voltage taps. The leads from the voltage tap wires connect to the control system wiring through current limiting resistors to reduce any current-voltage combination to within the class-1 Electrical Classification of the ES&H Manual.

3.20.2.2 Cryogenic Hazard

Nitrogen and helium are two types of cryogens used to keep the coils superconducting. The total volume of liquid helium and liquid nitrogen in Hall B is less than 900 liters and 130 liters, respectively. Proper insulation is installed on all piping accessible to personnel. In the event of a quench or loss of insulating vacuum event, relief valves on the helium and nitrogen circuits vent generated gas to the hall. In case of such event, Hall B remains ODH-0. In case of a power outage, the hall ODH rating would go up to ODH-2 after five hours. Appropriate ODH signs are posted at all entrances to the hall and an oxygen monitoring system is installed in the hall and operational.

3.20.2.3 Vacuum Hazard

The purpose of the vacuum system is to provide 10^{-5} Torr or better thermal insulating vacuum to six superconducting coils and one cryogenic distribution box. After liquid helium is introduced into the coils, a Loss of Vacuum (LOV) event with a full air inrush can lead to very high heat transfer to the helium and nitrogen circuits with a resulting phase change in the liquid helium and nitrogen and potential high pressure expulsion from the system. In the event of an LOV event, relief valves on the helium and nitrogen circuits vent generated gas to the hall.

3.20.2.4 Magnetic Field

When powered up to 3770 A, the torus can generate up to 3.58 T field close to the cold hub and up to 600 G in the zones that extend somewhat beyond the magnet boundaries. The 5 G boundary restricting access by personnel with surgical implants and bioelectric devices, the 200 G crane boundary, and the 600 G whole body boundary were found and recorded during the commissioning of the magnet. These contours are marked up and appropriate signage posted. Strong magnetic fields will attract loose ferromagnetic objects, possibly injuring body parts or striking fragile components. Prior to energizing the magnet, a sweep of the surrounding area must be performed

for any loose magnetic objects. All personnel entering the 600 G area will also be trained to remove ferromagnetic objects from themselves. To prevent personnel with surgical implants and bioelectric devices from entering the 5 G boundary, lighted warning signs are placed at the doors of the hall when the torus is energized, and flashing red beacons and personnel barricades are installed at the actual 5 G contour.

3.20.2.5 Stored Energy

At 3770 A, the total energy stored in the magnet is about 14.2 MJ. Upon sudden loss of hall electrical power or quench or LOV, the energy is dumped into a dump resistor.

3.20.3 Responsible Personnel

Individuals responsible for the CLAS12 torus system are (see Table 3.21):

Name	Dept.	Phone	email	Comments
Engineering on call		757-748-5048	—	1st contact
B. Miller	Hall B	x7867	miller@jlab.org	2nd contact
K. Bruhwel	Hall B	x7868	bruhwel@jlab.org	3rd contact

Table 3.21: Personnel responsible for the CLAS12 torus magnet system.

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