Experiment Safety Assessment Document (ESAD) for the Hall B CLAS12 Run Group D

Updated on July 6, 2023 for Run Group D (RG-D)

Contents

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 in Chapter 3120 of the Jefferson Lab EHS&Q 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 876-1743. For escalation of effort or for emergencies, the RadCon manager (Keith Welch) can be reached as follows: Office: 269-7212.

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/cm^2. 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 (Tim Minga) can be contacted at 269-7310.

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 Chapter 6200 of the Jefferson Lab EHS&Q manual and must obtain approval of one of the responsible personnel. The JLab electrical safety point-of-contact (Todd Kujawa) can be reached at 269-7006.

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 Chapter 6132 of the Jefferson Lab EHS&Q manual. Use of cranes, hoists, lifts, etc. must comply with Chapter 6141 of the Jefferson Lab EHS&Q 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 (Suresh Chandra) can be contacted at 269-7248.

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 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 Jerry Kowal at 269-7009 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 Will Oren 269-7344 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 EHS&Q manual. Machining of lead or beryllium, which are highly toxic in powdered form, requires prior approval of the EHS&Q 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 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 (Bert Manzlak) can be reached at 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 Run-Group M run. Many of these subsystems impose similar hazards, such as those induced by magnets and magnet 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-up 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.).

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 [**?**].

Additional safety information can be obtained from the following documents:

- ○ ES&H Manual [**?**]
- ○ PSS description document [4]
- ○ Accelerator Operations Directive [5]

3.3.3 Responsible Personnel

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

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.

3.4 Vacuum System

The Hall B vacuum system consists of three segments: the beam transport line to the experimental target, consisting of 1.5 in to 2.5 in diameter beampipes, the Hall B target vacuum chamber, and the vacuum beamline to the Hall B electron dump consisting of 2 in to 6 in diameter beampipes. For all experiments the first two segments are interconnected. There is a 1 in diameter, 2-mil-thick aluminum window on the exit of the target vacuum chamber and a 2 in diameter, 2-mil-thick window on the entrance of the vacuum beamline of the downstream segment. The first part of the CLAS12 Commissioning run will use solid targets. In this case all three segments are connected, and instead of the target vacuum chamber, a 2 in diameter beampipe will be used. The vacuum spaces can be isolated from one another via vacuum valves 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.

3.4.3 Responsible Personnel

The vacuum system will be maintained by the Hall B Engineering Group.

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 target system used for RG-D is the Hall B cryo target. This target system has just been assembled and will be used first by RG-D experiments. RG-D will use the following targets inside the Hall B cryo target system:

- Liquid:
    - Hydrogen
    - Deuterium
- Solid
    - Carbon
    - Copper
    - Tin

The target configuration includes a 5 cm long liquid cell for Hydrogen or Deuterium (LD2), plus a solid target flag system, as shown in Fig. 3.1 below. The flag system holds 2 carbon targets in series or a copper and a tin target in series. The flag system is mounted in series with the liquid cell. The flag system can be remotely operated to put the carbon targets in the beam, no solid targets in the beam, or the copper and tin targets in the beam.

The targets are housed in a vacuum vessel along with the cryogenic system. A scattering chamber is installed around the target cell area. This is made from Rohacell foam with a wall thickness of 6.5 mm. Aluminum windows are used at the entrance and exit of the liquid cells, and at the exit of the scattering chamber. The details of all components, such as windows and cells, are shown on the beam line drawing, including thicknesses and locations. The beam line drawings can be found at https://clasweb.jlab.org/wiki/index.php/User:Cwiggins.

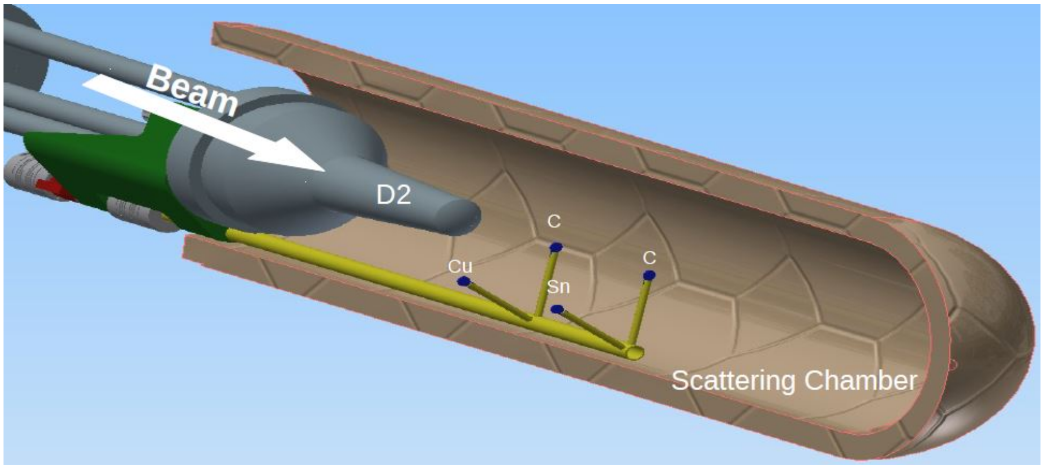

Figure 3.1: The flag design with the 5 cm apart foils mounted on the same shaft (bottom yellow rod) with ≈ 55 degrees opening between their holding yellow needles that rotate together with a stepper motor. Each set of two foils will be inserted in the beamline in series with an empty LD2 target.

3.5.1 Hazards

The cryogenic target contains a condensed cryogenic fluid and is considered a pressure vessel. Sudden warming of the target due to a vacuum breach could result in rapid expansion of the target fluid. The system is designed to safely vent the excess pressure. Failure of the foam scattering chamber, or the thin window of the scattering chamber could produce a loud noise and could result in a failure of the target integrity.

The target utilizes flammable gas (hydrogen) during operation. Failure of the system could release flammable gas into the hall. The target gases and the helium used in the target refrigerator are potential ODH risks, and failure of either system could reduce the oxygen levels in the hall.

The target cell system is protected by 15 psi relief valves. The target operates in a vacuum chamber, so the total pressure difference possible across the cell is 15 psi + 14.7 psi= 29.7 psi. The cell is considered a pressure vessel. If the Kapton cell ruptures, the target gas would vent into the target vacuum space and the vacuum pumps would turn off. If the vacuum space pressure increases to 1 psi, the target gas will go out of the vacuum space relief valve and be discharged out of the Hall. No target gas would enter the Hall.

3.5.2 Mitigations

The design and construction of the entire Hall B cryo target is in accordance with AMSE standards. During operation, the foam scattering chamber, and the thin window are surrounded by the Hall-B CLAS12 Central Detectors and are therefore difficult to access. A protective shield will be placed around the scattering chamber whenever the target is retracted from the Central Detector system and is under vacuum. Personnel working near the target shall wear hearing and eye protection whenever the foam extension and window are exposed and the system is under vacuum. No cold cryogenic components are accessible by personnel.

Relief valves are installed in all the target pressure circuits so the safety system is entirely passive. The quantity of flammable gas (H2) is less than 80 g and is therefore considered a class-O installation (!600 g) and the rules and regulations for this installation shall be followed, notably:

- 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.

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

3.5.3 Responsible Personnel

The target system will be maintained by the JLab Target Group.

3.6 Hall B Gas System

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

Name	Department.	Phone	email	Comments
James Brock	Target Group	(757) 871-5374	`jbrock@jlab.org`	1st contact
Chris Keith	Target Group	(757) 746-9277	`ckeith@jlab.org`	2nd contact
Engineering on call	Hall B	(757)-748-5048		3rd contact

Table 3.3: Personnel responsible for the CLAS12 target system.

1. Forward Drift Chambers
    - 10% CO_2 in Argon at 0.075 inch wc
    - N_2 purge for external HV components at atmospheric pressure
2. LTCC
    - C_4F_{10} at 1.0 – 4.0 inch wc
    - N_2 purge for C_4F_{10} recovery at 1.0 – 4.0 inch wc
3. MVT
    - 10% C_4H_{10} in Argon - 30 psi
    - 10% CF_4 10% C_4H_{10} in Argon - 30 psi
4. RICH
    - N_2 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
    - CO_2 purge at 0.150 inch wc
6. FT
    - 10% C_4H_{10} in Argon - 30 psi
    - N_2 purge for calorimeter at atmospheric pressure
7. SVT

- Dry air purge 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 four baseline detectors (DC, HTCC, LTCC, SVT). Additionally, it also controls and monitors gas supply to three non-baseline detectors (RICH, MVT, FT).

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 will be controlled. All system chassis are electrically grounded to the racks, and each contains an over-current protection fuse.

3.6.1 Hazards

The following cryogens are used at the 96B Gas Shed at the following pressures;

- Liquid Argon - $175 - 200$ psi
- Liquid Nitrogen - 45 psi
- Liquid CO_2 - $160 - 300$ psi

The following gases are produced from cryogen boil off;

- Ar - $160 - 200$ psi
- CO_2 - $160 - 200$ psi
- N_2 - 35 psi

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

- Ar - $40 - 200$ psi

- CO_2 - 15 – 200 psi
- CF_4 - 40 psi
- C_4F_{10} - 4 – 50 psi
- C_4H_{10} - 40 psi
- N_2 - 35 psi

The following gas mixtures are produced at the following pressures;

- 10% CO_2 in Argon - 100 psi
- 10% C_4H_{10} in Argon - 30 psi
- 10% CF_4 10% C_4H_{10} in Argon - 30 psi

The two MVT gas mixtures are flammable;

- 10% C_4H_{10} in Argon - 30 psi
- 10% CF_4 10% C4H6 in Argon - 30 psi

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

- 10% CO_2 in Argon - $<$ 5 psi
- 10% C_4H_{10} in Argon - 30 psi
- 10% CF_4 10% C_4H_{10} in Argon - 30 psi
- N_2 - 35 psi
- CO_2 - 15 psi
- C_4F_{10} - 4 – 8 psi

3.6.2 Mitigations

The 1500 gallon liquid-argon dewar and 160 liter liquid CO_2 dewar are used for gas supply only. The dewars have relief valves preventing over-pressure.

Liquid nitrogen is used in both gas and liquid states. The 1500 gallon LN_2 dewar has a relief valve preventing over-pressure.

N_2 gas is used as a purge gas for detectors and other equipment. The purge flow is controlled by mass flow controllers or flow rotometers and discharges to the atmosphere.

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 N_2 purge for the endplate electronics is controlled by rotometers in the 96B Gas Shed. This purge discharges at atmospheric pressure.

2. 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 N_2 is used to cool the C_4F_{10} distillation unit in the 96B Gas Shed in order to condense and recover C_4F_{10} for reuse. The distillation unit has a relief valve preventing overpressure. The N_2 discharge flows through heat exchangers and vents to atmosphere at ambient temperature and pressure.

3. 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.

4. The FT calorimeter has a N_2 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.

5. The HTCC CO_2 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.

6. 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 N_2 purge for the aerogel discharges to the atmosphere. There are EPICS-based alarms to alert personnel of high or low pressure.

7. The SVT uses a dry air purge in the local air volume to reduce humidity. There are EPICS-based alarms to alert personnel of high or low flow.

3.6.3 Responsible Personnel

Individuals responsible for the gas systems are:

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 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.

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 system are:

Name	Dept.	Phone	email	Comments
Sergey 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 providing 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 CO_2 gas at room temperature and low positive differential pressure. It is directly connected to a CO_2 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 the HTCC entry or exit composite windows failure (rupture or separation due to fatigue of the epoxy glue joints) leading to significant CO_2 gas leaks.
4). Hazard of rupture of the HTCC entry or exit composite windows leading to a sudden release of CO_2 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 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 OSP "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.

3.8.3 Responsible Personnel

Individuals responsible for the HTCC system are:

Name	Dept.	Phone	email	Comments
Expert on call				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/CO_2 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 μA) are set. All mechanical structures are properly grounded. There are possible electrical hazards if a malfunctioning HV board 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. The same risk codes and mitigation applies to the procedure known as a "minimal disconnect" in which an individual HV pin is removed from the HV distribution box.

- 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:

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
Florian Hauenstein	Hall B	(757)-746-3395	`hauenst@jlab.org`	2nd contact
Morgan Cook	Hall B		`mcookiv@jlab.org`	3rd contact

Table 3.7: Personnel responsible for the CLAS12 DC system.

Cook, Morgan TED 1546-19 mcookiv

3.10 Low Threshold Cherenkov Counter

The CLAS12 Low Threshold Cherenkov Counter (LTCC) is composed of six identical detectors. 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.

3.10.1 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.

3.10.2 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.

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

3.10.3 Responsible Personnel

Individuals responsible for the LTCC system are:

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
M. Ungaro	JLab	(757)-269-7578	`ungaro@jlab.org`	2nd contact

Table 3.8: Personnel responsible for the CLAS12 LTCC system.

3.11 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.

3.11.1 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 1527LC mainframes or CAEN 4527 mainframes outfitted with negative polarity 24-channel A1535N modules. The typical settings for each channel are: $V = -2000$ V, $I = 350\ \mu$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.

The panel-1b and panel-1a counters are positioned between the PCAL and LTCC 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.

3.11.2 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. All work is carried out in conjunction with input from the FTOF Group Leader and the Hall B Work Coordinator.

3.11.3 Responsible Personnel

Individuals responsible for the FTOF system are:

Name	Dept.	Phone	email	Comments
FTOF/CTOF on call	Hall B	(757)-344-7204		1st contact
D.S. Carman	Hall B	757-269-5586	`carman@jlab.org`	2nd contact

Table 3.9: Personnel responsible for the CLAS12 FTOF system.

3.12 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.

3.12.1 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.

3.12.2 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.

3.12.3 Responsible Personnel

Individuals responsible for the EC system are:

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

Table 3.10: Personnel responsible for the CLAS12 EC system.

3.13 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.

3.13.1 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 a CAEN SY1527 mainframes outfitted with negative polarity 24-channel A1535N modules. The typical settings for each channel are: $V = -2000$ V, $I = 350$ μA. 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) that must be mitigated.

During testing 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.

3.13.2 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.

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°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. Normally no servicing 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. However, there are specific situations where the upstream PMTs need to be accessed with the field on and personnel will be working within the 1 kG fringe field of the magnet. Personnel working in the proximity of the solenoid when it is energized must be concerned with the following hazards:

- Danger of metal objects being attracted by the magnet fringe field and becoming airborne, possibly pinching body parts or damaging equipment,
- Danger of cardiac pacemakers or other electronic medical devices no longer functioning properly in the presence of magnetic fields,

- Danger of metallic medical implants (non-electronic) being adversely affected by magnetic fields,
- Loss of information from magnetic data storage driver such as tapes, disks, credit cards, etc.

Only trained and qualified CTOF personnel may work on the CTOF system (and only at the location of the upstream PMTs) with the solenoid energized. This is important to minimize danger to personnel and to the detectors themselves. 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.

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. All work is carried out in conjunction with input from the CTOF Group Leader and the Hall B Work Coordinator.

3.13.3 Responsible Personnel

Individuals responsible for CTOF the system are:

Name	Dept.	Phone	email	Comments
FTOF/CTOF on call	Hall B	(757)-344-7204		1st contact
D.S. Carman	Hall B	757-269-5586	`carman@jlab.org`	2nd contact

Table 3.11: Personnel responsible for the CLAS12 FTOF system.

3.14 Silicon Tracker

The CLAS12 SVT is a barrel-shaped tracking detector that has a wide azimuthal angular coverage and $\sim 2\pi$ coverage in polar angle. It has four polygonal regions, R1 - R4, that have 10, 14, 18, and 24 sectors, respectively. Each sector contains modules, whose top and bottom sides have three, 320-μm-thick, silicon sensors that are wire bonded together, a pitch adapter, and a readout hybrid - part of the readout electronics located on the hybrid flex circuit board (HFCB). The bottom side of the module, closer to the beam, is referred to as the U layer; the top side of the module is referred to as the V layer. Each side of the module has 256 readout strips.

Module services provide power, cooling, and communication to all the SVT modules. The services connected to the SVT include: power supply cables, data and control cables, cooling pipes, and cables for monitoring humidity and temperature. The power supply system consists of low voltage and high voltage supplies, and MPOD crates. The low voltage supply powers the analog and digital portions of the readout chips. The high voltage supply is for biasing the sensors and monitors the leakage current over a wide range. The normal operating point of reverse bias for the SVT sensor is 85 V. Each side of the module receives low voltage, 2.5 V for both the analog and digital parts of the FSSR2 chip and high voltage for the sensors. The low voltage also powers analog output CMOS IC temperature sensors, one per side.

The front-end chips of the SVT modules have to be cooled to ensure normal operating conditions. The cooling system of the SVT consists of the portable chiller, plastic cooling tubes, flow meters, and the cold plates with copper tubes inside circulating liquid coolant. The SVT dry air purging system is designed to provide a dry environment inside the detector and to avoid condensation.

3.14.1 Hazards

Hazards to personnel include the high voltage that biases the sensors and the low voltage current that powers the readout electronics. During the installation phase, mechanical hazards include the risks associated with lifting the SVT during integration, transportation, and installation, and the work at height in order to access the crates and patch panel on the insertion cart.

Hazards to the SVT itself include mechanical damage, radiation damage, gas over-pressure, cooling system leaks, and overheating. Overheating can occur in the SVT if the cooling system is performing inadequately or if a cooling system leak develops.

Radiation damage could occur in the SVT if the beam moves into the sensors, the beam interacts upstream to produce excessive radiation, or excessive beam currents create more radiation than can be tolerated.

Wrong LV settings could damage the hybrids and ambient sensors; wrong HV settings could cause high leakage current that could damage the sensors.

Failure of the crate cooling fans could cause overheating and damage of the crate modules.

Overpressure in the cooling lines could cause damage of the cooling system.

3.14.2 Mitigations

Electrical hazards (personnel):

- Hazards to personnel are mitigated by turning off HV and LV power before disconnecting cables or working on the sensors and electronics.

Mechanical hazards (personnel):

- Hazards related to work at height during installation and maintenance is mitigated by proper safety training and using certified step ladders or scaffolding.
- Mitigation of hazards to the personnel related to the SVT lifting is done by admitting only trained JLab staff, using personal protection and certified gantry, cranes, and tooling.

Mechanical hazards (detector):

- Possible mechanical damage has been mitigated by following the proper procedures for each job and using the special tooling.
- All operations related to handling the SVT are performed only by trained personnel with hands on experience working with the SVT.
- Lifting the SVT during the installation and maintenance is performed only by properly trained personnel using certified equipment.
- SVT integration with the MVT is done only by the trained personnel following the proper procedures.

Radiation damage hazards (detector):

Radiation damage from the beam is mitigated in several steps.

- Beam size and halo must conform to beam requirements before beam is passed through the detector.
- An upstream collimator is aligned with the "centered" beam position to intercept the beam if it moves off nominal position.
- Beam halo monitors sense a rise in backgrounds if the beam moves off its nominal position, activating the beam Fast Shutdown (FSD).

Other detector hazards:

- Cooling system: Overheating is mitigated by leak checks, requiring good coolant flow and pressure, proper coolant temperature, and sensor temperatures in the working range. The cooling system is constantly monitored by an EPICS IOC, logged to a MYA database, and interlocked to the HV and LV power systems, and the alarm handler. There are interlocks on coolant leaks, hybrid temperature and humidity, ambient temperature, humidity, and dew point. All temperature and humidity sensors are redundant.
- Electronics and sensors: Power supplies have hardware and software limits set, and currents and voltages are controlled, monitored, and included in the alarm handler. Crate temperatures are monitored by the control system. The proper HV/LV power supply ramp up and ramp down sequence is ensured by the Slow Controls software to prevent human mistakes.
- Gas system: To prevent condensation and gas over-pressure, the gas flow of the nitrogen purging is controlled, interlocked, and monitored by the Slow Controls system.
- The hardware interlock system provides redundant safety for critical parameters in case of alarm handler failure.
- Control system parameters and settings can be saved and restored.

3.14.3 Responsible Personnel

Individuals responsible for the SVT system are:

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
Y. Gotra	JLab	(757)-269-5571	`gotra@jlab.org`	2nd contact
B. Eng	JLab	(757)-269-6018	`beng@jlab.org`	3rd contact
R. Paremuzyan	JLab	(757)-541-7539	`rafopar@jlab.org`	4th contact

Table 3.12: Personnel responsible for the CLAS12 SVT 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 $\sim$ 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

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:

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	JLab	(757)-269-5586	`carman@jlab.org`	JLab contact

Table 3.13: Personnel responsible for the CLAS12 CND system.

3.16 Micromegas Vertex Tracker

The CLAS12 Micromegas Vertex Tracker apparatus is comprised of the Barrel Micromegas Tracker (BMT) and the Forward Micromegas Tracker (FMT), which despite their different shapes (cylinders or disks), are the same type of detector and therefore have the same list of hazards. Both subsystems are gaseous detectors, the only difference with respect to the hazards is the use of different gases for the BMT and the FMT.

The BMT is composed of 3 double-layers of resistive cylindrical Micromegas detectors, each layer is divided into 3 sectors, for a total of 18 detectors. In combination with the Silicon Vertex Tracker, the BMT covers the polar angle region from 35° to 125° around the target. Micromegas detectors are double-stage gaseous detectors. The gas that will be used for the BMT is a mixture of 90% argon 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 BMT is powered by two high voltages up to 2000 V, although the current limit for both HV is extremely low. The detectors are read out through 1.5-m-long 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, on the back of the support tube holding the MVT. They are powered through low voltage, and kept within the 40°C to 60°C temperature range using a simple set of fans and tubing.

The FMT is composed of 6 flat resistive Micromegas detectors. Each detector is divided in two zones (inner and outer). The FMT covers the polar angle region from 6° to 29° from the target. Micromegas detectors are double-stage gaseous detectors. The gas that will be used for the BMT 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 FMT is powered by three high voltages up to 2000 V, although the current limit for all three HV is extremely low (<1 mA). The detectors are read out through 2.2-m-long 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, located on the back of the support tube holding the MVT. They are powered through low voltage, and kept within the 40°C to 60°C temperature range using a simple set of fans and tubing.

All hazards and mitigation options for the FMT are the same as for the BMT. Even though the shapes of the detectors vary, they are almost identical in principle. The gas mixture is however different, but the amount of flammable gas (isobutane) is almost the same.

3.16.1 Hazards

Hazards to personnel include the use of flammable gas, high voltage, and the low voltage that powers the readout electronics. During the installation phase, mechanical hazards include the risks associated with the weight of the MVT, including its support tube, as well as the work at height in order to access the LV and gas control crates.

Hazards to the MVT detectors themselves include mechanical damage, gas leaks, and gas over-pressure. Also, there is a risk of damage to the MVT during installation in the solenoid bore.

Hazards concerning the MVT Front-End Units include: wrong LV settings that could damage the FEUs, and absence of cooling or cooling failure that would overheat the cards.

3.16.2 Mitigations

Fire hazards (equipment and personnel):

- Use of flammable gas: All MVT detectors use 10% isobutane, which is flammable. Mitigation: the amount of isobutane in our system is very limited. For both the BMT and FMT detectors, the total combustion energy is equivalent to less than 12 g of hydrogen, which makes it a class-0 gas system (class-1 starts at 600 g).

Electrical hazards (personnel):

- High Voltage: high voltage up to 2500 V are used routinely for all detectors. Mitigation: very low current limit (10 μA) is set. All mechanical structures are properly grounded.
- Low Voltage: In order to power up the front-end electronics, we use low voltage at 4.5 V with 60 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 and shielded.

Mechanical hazards (personnel):

- Heavy object (Total: 200 kg), handled with an overhead crane. Mitigation: job done by trained JLab staff according to and compliant with the Jefferson Lab EHS&Q manual.
- Work at height for access to gas control and LV crate (located at 2.5 m height) on the moving cart. Mitigation: use of certified step ladder provided by JLab.

Other hazards to MVT:

- Detectors: gas over-pressure, gas leaks, and mechanical damage. Mitigation: gas control system with over-pressure and leak limits. Protection covers (1 mm carbon shell) in order to avoid as much as possible damage to the detectors before installation and operation. The FMT 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.

- Installation of Central Tracker: Damage to the MVT during installation in the solenoid bore. The CTOF is the closest detector to MVT. Mitigation: Parts of the MVT that are radially farthest outwards are surveyed prior to insertion into the solenoid to ensure that there is no interference with adjacent CTOF components. There is a large clearance (∼11 mm) between the MVT and the adjacent detector, CTOF. The insertion will be achieved on a precision rail system that is used for the target insertion. There will be a constant visual check as the MVT is inserted into the solenoid bore. A linkage mechanism on the upstream end of the SVT/MVT allows for the adjustments in pitch and yaw if needed. Finally, the operation will be performed by trained personnel with several years of experience and familiar with similar positioning.
- Electronics: wrong LV settings and absence of cooling or cooling failure. Mitigation: Slow Controls read-back of LV settings 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 temperature goes beyond a predefined threshold, the cards are gracefully shut-down automatically.

3.16.3 Responsible Personnel

Individuals responsible for the MVT system are:

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
Y. Gotra	JLab	757-269-5571	`gotra@jlab.org`	2nd contact
R. Paremuzyan	JLab	757-269-7539	`rafopar@jlab.org`	3rd contact
M. Defurne	Saclay	+33169083237	`maxime.defurne@cea.fr`	4th contact

Table 3.14: Personnel responsible for the CLAS12 MVT system.

3.17 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 and will replace one sector of the existing LTCC detectors. The Ring Imaging Cherenkov Counter incorporates:

1. Aerogel radiator. Aerogel is very light material, non-toxic, and nonflammable but hygroscopic.

2. Focusing mirror system. Mirrors reduce the detection area instrumented by the photo-detectors to ~ 1 m^2.

3. Photo-detector. The photo-detector includes 391 Hamamatsu multianode photomultipliers (MAPMTs). Each MAPMT has 64 pixels, so the the detector has 25024 channels.

4. High Voltage. High voltage is supplied to each MAPMT. The MAPMT high voltage will be less than 1100 V and the divider current is 225 μA. The power consumption for all MAPMTs is $\sim$ 100 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 will be not 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 m^3) 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.

3.17.1 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.

3.17.2 Mitigations

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.

Name	Dept.	Phone	email	Comments
Expert on call	Hall B			1st contact
V. Kubarovsky	Hall B	x5649	`vpk@jlab.org`	2nd contact
M. Mirazita	INFN	x6273	`mirazita@jlab.org`	3rd contact
M. Contalbrigo	INFN	x6273	`mcontalb@jlab.org`	4th contact
A. Kim	UConn	x6356	`kenjo@jlab.org`	5th contact

Table 3.15: Personnel responsible for the CLAS12 RICH detector.

3.17.3 Responsible Personnel

Individuals responsible for the RICH detector are:

3.18 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.

3.18.1 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.

3.18.1.1 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.

3.18.1.2 Mitigations

Mitigation of risks associated with FT-Cal operations are achieved in the following ways:

- 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.

3.18.1.3 Electrical Hazards 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 μA) 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 ±5 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.

3.18.1.4 Electrical Hazards 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.

3.18.1.5 Other Hazards 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.

3.18.1.6 Responsible Personnel

Individuals responsible for the FT-Cal system are:

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
M. Battaglieri	INFN	x7266	`battagli@jlab.org`	2nd contact
R. De Vita	INFN	x7266	`devita@jlab.org`	3rd contact

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

3.18.2 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.

3.18.2.1 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 overcurrent 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.

3.18.2.2 Mitigations

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.

3.18.2.3 Responsible Personnel

Individuals responsible for the FT-Hodo system are:

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

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

3.18.3 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 as 768 strips with 560 μm pitch. The FT tracker covers the polar angle region from 2.5° to 4.5° from the target. The gas that will be used 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 the 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.

3.18.4 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.

3.18.5 Mitigations

Mitigation of risks associated with then FT-Trk operations are achieved in the following way:

- 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 will be 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.

3.18.5.1 Fire Hazards Mitigation (Equipment and Personnel)

Use of flammable gas: the FT tracker 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: 269-6638, Cell: (540)-729-0095.

3.18.5.2 Electrical Hazards Mitigation (Personnel)

High Voltage: high voltages up to 2000 V are used routinely for the detectors. Mitigation: very low current limit (10 μA) 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.

3.18.5.3 Other Hazards Mitigation

Detectors: gas over-pressure, gas leaks, mechanical damage. Mitigation: gas control system with over-pressure and leak limit detection by flowmeter (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.

3.18.5.4 Responsible Personnel

Individuals responsible for the FT-Trk system are:

Name	Dept.	Phone	email	Comments
Expert on call				1st contact
R. Paremuzyan	JLab	757-541-7539	`rafopar@jlab.org`	2nd contact
Y. Gotra	JLab	757-269-5571	`gotra@jlab.org`	3rd contact
R. De Vita	INFN	757-269-7266	`devita@jlab.org`	4th contact

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

3.19 Backward Angle Neutron Detector

The Backward Angle Neutron Detector (BAND) is placed at the top of the SVT 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 $7.2 \times 7.2\,\mathrm{cm}^2$ 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 beam line and target installation. All bars are read-out on both sides 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 left of BAND in beam direction. 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 are 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 $1\,\mu$J per pulse at 0.3 ns width (FWHM) which will be attenuated and distributed to all fiber outputs which have an output of about 200 pJ. The fibers are connected via a patch panel to each scintillator bar.

3.19.1 Hazards

3.19.1.1 Electrical hazard

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

3.19.1.2 Fall hazard

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

3.19.1.3 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.

3.19.1.4 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 $\approx 200\,\text{pJ}$. 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.

3.19.2 Mitigations

3.19.2.1 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 ($< 1\,\text{mA}$). 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.

3.19.2.2 Fall hazard mitigations

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

3.19.2.3 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 sort of 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.

3.19.2.4 Laser hazard mitigations

The laser calibration system is a closed system with fibers connected to the scintillator bars via a patch panel. All of this 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 ($\approx 200\,\text{pJ}$), 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 will be 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 LOSP.

3.19.3 Responsible personnel

Individuals responsible for the system are:

Name	Dept.	Phone	email	Comments
Band on call		(757)310-7198		1st contact
F. Hauenstein	JLab		`hauenst@jlab.org`	2nd Contact
O. Hen	MIT		`hen@mit.edu`	3nd Contact
L. Weinstein	ODU		`weinstein@jlab.org`	4th contact

Table 3.19: Personnel responsible for the Backward Angle Neutron Detector.

3.20 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 Central Vertex Tracker (SVT and MVT), 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.

3.20.1 Hazards

The hazards of the Solenoid magnet include the following:

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

3.20.2 Mitigations

3.20.2.1 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 OSP 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 EHS&Q 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 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.

3.20.2.3 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.

3.20.2.4 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 will 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 will 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.

3.20.2.5 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.

3.20.3 Responsible Personnel

Individuals responsible for the Solenoid system are:

Name	Dept.	Phone	email	Comments
Engineering on call	Hall B	(757) 748-5048	–	1st contact
B. Miller	Hall B	x7867	`miller@jlab.org`	2nd contact
K. Bruhwel	Hall B	x5577	`bruhwel@jlab.org`	3rd contact

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

3.21 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 $2 \times 4 \times 0.05$ 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.

3.21.1 Hazards

The hazards of the Torus magnet include the following:

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

3.21.2 Mitigations

3.21.2.1 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 OSP 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 EHS&Q Manual.

3.21.2.2 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.

3.21.2.3 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.

3.21.2.4 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 will 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 will 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.

3.21.2.5 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.

3.21.3 Responsible Personnel

Individuals responsible for the Torus system are:

Name	Dept.	Phone	email	Comments
Engineering on call	Hall B	(757)-748-5048	–	1st contact
B. Miller	Hall B	x7867	`miller@jlab.org`	2nd contact
K. Bruhwel	Hall B	x5577	`bruhwel@jlab.org`	3rd contact

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

Bibliography

[1] CEBAF Hot Check-Out db page (accessible from inside JLab only) URL:https://accweb.acc.jlab.org/hco/

[2] EPICS Documentation. URL: http://www.epics.org/. See also http://www.aps.anl.gov/asd/controls/epics/EpicsDocumention /WWWPages/EpicsDoc.html

[3] JLab EHS&Q Manual. URL: http://www.jlab.org/ehs/ehsmanual/.

[4] JLab/CEBAF Personnel Safety System (PSS) Manual. URL: http://www.jlab.org/eng/ssg/user_info.html

[5] Accelerator Operations Directive.
URL: http://www.jlab.org/ops_docs/online_document_files/ACC_online_files/ accel_ops_directive.pdf (URL is available inside JLab site).