# Chapter 2

# The Near Neutrino Detector: A Fine-Grained Tracker

ch:nd-nnd

## 2.1 Introduction

c:nd-nnd-intro

The DUNE Fine-Grained Tracker (FGT) near detector consists of a straw-tube tracking detector (STT) and electromagnetic calorimeter (ECAL) inside of a 0.4 T dipole magnet. In addition, Muon Identifiers (MuIDs) are located in the steel of the magnet, as well as upstream and downstream of the STT. The FGT is designed to make precision measurements of the neutrino fluxes, cross sections, signal rates, and background rates. This document presents

remove 'an overview of'

the FGT design, which will meet the physics goals and sensitivities of the DUNE experiment.

cross-ref where these are listed

## 2.2 Motivation

nnd-motivation

In order for DUNE to achieve the desired neutrino-oscillation sensitivity, the charged-current signal events and neutral-current background events in the DUNE far detector (FD) must be precisely predicted as a function of the parameters and variables that affect oscillations. These include energy, leading lepton (which tags the neutrino flavor) and the momentum and identification of particles generated by neutrino interactions. At the FD, the first and the second oscillation maxima signals occur at about 2.4 GeV and 0.8 GeV, respectively – an energy regime where neutrino cross sections and fluxes have large uncertainties. It is therefore crucial to measure the unoscillated neutrino fluxes and their interactions at the near site.

In addition to the oscillation signal, it is critical to identify and measure processes such as neutral current $\pi^0$ production, that can mimic oscillation signals at the FD. Thus, the principal focus of the neutrino detector will be on the neutrino-oscillation energy range of $E_\nu < 8$ GeV, as well as higher neutrino energies that produce background to the oscillation signal. Furthermore, the $8 < E_\nu < 20$ GeV energy range can be used as a "control region" i.e., as a region to search for physics beyond the PMNS matrix. Clearly, the measurements must be comparable to those made in the FD, for which the target material is liquid argon (LAr).

Finally, the neutrino detector must measure nuclear effects, including short-range correlations, two-body currents, pion absorption, initial-state interactions, and final-state interactions. These nuclear effects have an impact on neutrino cross sections and energy determinations, and differences between neutrinos and antineutrinos must be fully understood when searching for CP violation.

The proposed detector will constrain the systematic uncertainties in the DUNE oscillation measurements. Regardless of the process under study, the systematic error should be less than the corresponding statistical error. The design presented here is the subject of study within the DUNE Science Collaboration. As these studies progress, the design of the DUNE near neutrino detector, referred to as the Fine Grained Tracker (FGT) in this document, may evolve from what is described here.

## 2.3 Overview of FGT Design

sec:nd-nnd-fgt

fig:STT_schematic

A schematic drawing of the FGT design is shown in Figure 2.1. The fine-grained tracker will measure the neutrino event rates and cross sections on argon, water, and other nuclear targets for both $\nu_e$ and $\nu_\mu$ charged current (CC) and neutral current (NC) scattering events. The FGT design consists of a straw-tube tracker (STT), consisting of straw tubes, water targets, argon targets, and radiator targets, and an electromagnetic calorimeter (ECAL), both inside a dipole magnet. In addition, muon detectors (MuID) consisting of resistive plate chambers (RPCs) will be embedded in the steel of the magnet.

The FGT has excellent position and angular resolutions due to its low-density ($\sim$ 0.1 g/cm$^2$) and high-precision STT. This high resolution is important for determining the neutrino vertex and determining whether the neutrino interaction occurs in the water or argon target. The proposed $3.5 \times 3.5 \times 6.4$ m$^3$ STT's position inside the dipole magnet with magnetic field, $B = 0.4$ T will enable particle tracking.

check edits

The nominal active volume of the STT corresponds to 8 tonnes (metric tons, t) of mass.

This makes me ask - how much water, how much argon?

tab:comparison tab:STT_specs

Table 2.1 summarizes the performance for the FGT configuration, and Table 2.2 lists the specifications for the FGT.

What's listed there is not a set of requirements; they're specs that we hope follow from requirements!

Given a 120-GeV proton beam

that leads to a neutrino flux of ...?

, the neutrino event rates in the detector will be $\sim 0.35 \times 10^{-14}$ events/tonne/proton on target. Assuming $0.5 \times 10^{14}$ protons per beam spill, this corresponds to $\sim 1.5$ events per spill in the 8-t active volume of the FGT design. Overlaps between interactions are expected to be manageable thanks to the nanosecond-level timing of the FGT relative to the $\sim 10\mu$s beam spill length.

the FGT overview image has whitespace at left; needs trimming in source app then reconversion to PDF. Also, this diagram should have labels to show each system in it

Table 2.1: A summary of the performance for the FGT configuration

tab:comparison

| **Performance Metric** | FGT |
|---|---|
| Straw Tube Detector Volume | 3.5m x 3.5m x 6.4m |
| Straw Tube Detector Mass | 8 tonnes |
| Vertex Resolution | 0.1 mm |
| Angular Resolution | 2 mrad |
| $E_e$ Resolution | 5% |
| $E_\mu$ Resolution | 5% |
| $\nu_\mu/\bar{\nu}_\mu$ ID | Yes |
| $\nu_e/\bar{\nu}_e$ ID | Yes |
| NC$\pi^0$/CCe Rejection | 0.1% |
| NC$\gamma$/CCe Rejection | 0.2% |
| CC$\mu$/CCe Rejection | 0.01% |

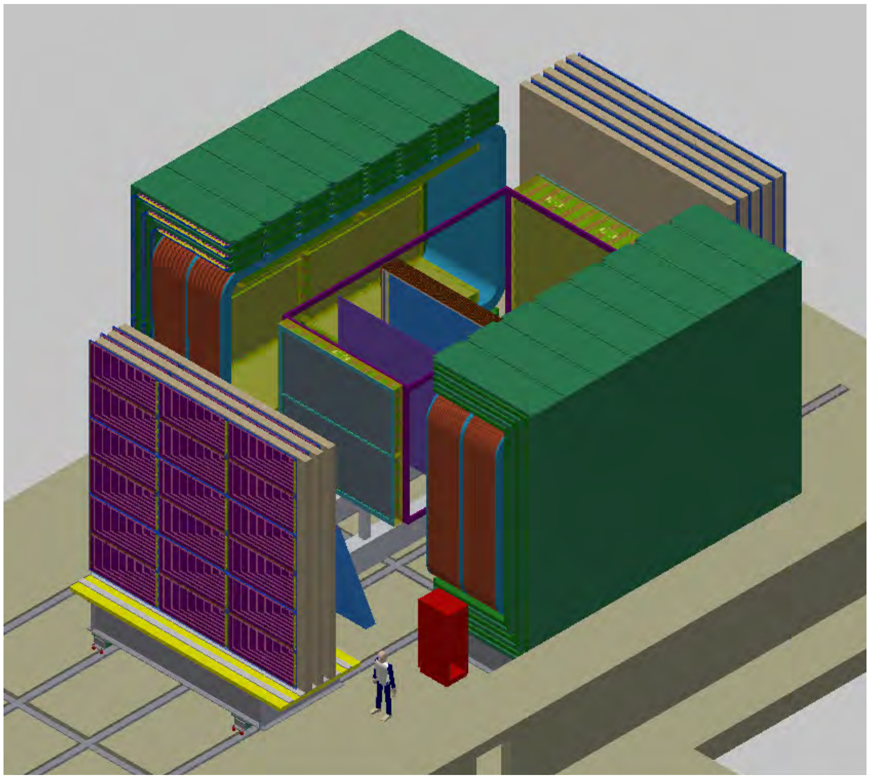

Figure 2.1: A schematic drawing of the fine-grained tracker design fig:STT_schema

Table 2.2: Specifications for the FGT

| Item | Requirement |
|---|---|
| Inner Magnetic Volume | 4.5m x 4.5m x 8.0m |
| Tracking Detector | 3.5m x 3.5m x 6.4m; 80 modules; 107,520 straws |
| Targets | 1.27-cm thick argon, water, and other nuclear targets |
| Transition Radiation Radiators | 3.6-cm thick radiators |
| ECAL | $X_0$ = 10 barrel, 10 backward, & 20 forward; 26,112 scintillator bars |
| Dipole Magnet | 0.4T; 2.4 MW; 60 cm thick steel |
| Magnetic Field Uniformity | $< 2\%$ magnetic field variation over inner volume |
| MuID | 432 RPC modules interspersed between 20-cm thick layers of steel |

tab:STT_specs

These are not requirements in the table, they are specifications; I changed the title

## 2.4 Straw-Tube Tracking Detector

c:nd-nnd-straw

### 2.4.1 Straw Tubes

The Straw-Tube Tracking Detector (STT) at the center of the FGT will be composed of straw tubes with an outer diameter of 1 cm, as well as radiators and targets.

Need something that says how the radiators and targets fit in with the straw tubes

Vertical (YY) and horizontal (XX) planes of straws

this needs a diagram to show how XX and YY planes are arranged

will be alternated and arranged in modules, with each module containing close-packed double straw layers of vertical and horizontal straws (XXYY). A schematic drawing of an STT module is shown in Figure STT_Detail ??.

I added ref to figure

An alternative design has also been considered; it calls for two planes of straws per module, XX, YY, and so on. It will have approximately the same number of total straw tubes in the tracker but twice as many modules.

Is there a schematic of it?

The performance and the cost of the STT are expected to be similar in both the reference (4-Planes/Module) and alternative (2-Planes/Module) designs.

In both designs?

The straw tubes will be filled with a gas mixture of either 70% Ar plus 30% $CO_2$ (for modules with targets) or 70% Xe plus 30% $CO_2$ (for modules with radiators). The dimensions of each module

in the reference design?

will be approximately 350 cm × 350 cm × 8.0 cm, including target or radiator planes and four straw planes. For ease of construction and transportation, each module is made up of six sub-modules, with dimensions of appproximately 350 cm × 117 cm × 2.0 cm. The straw tubes in a single sub-module will be able to provide the tension for the wires, however, a temporary sub-module carbon composite frame will be employed for shipping. The sub-modules will be assembled into modules at Fermilab, where each module will have a carbon composite frame around the perimeter of the module for support

This is different from the frame used for shipping? Pls clarify

and will have an attached target or radiator. Nominally, there will be 34 modules with targets and 46 modules with radiators, still keeping the average density of the STT at around 0.1 g/cm$^3$. Figure fig:STT_Detail 2.2 shows a schematic drawing of an STT module with four straw-tube planes and radiators.

The STT will have a total of 107,520 straws — corresponding to 336 straws per plane, 1344 straws per module — and 80 modules. Both ends of the straw tubes will be read out, leading to a total number of electronics channels of 215,040. The total mass of the STT, including targets and radiators, is approximately 8 tonnes, corresponding to an average density of 0.1.

prev sentence already said

The thickness of the entire 6.4-m-long STT is almost two radiation lengths. Specifications for the Straw Tube Detector are shown in Table tab:STT_details 2.3.

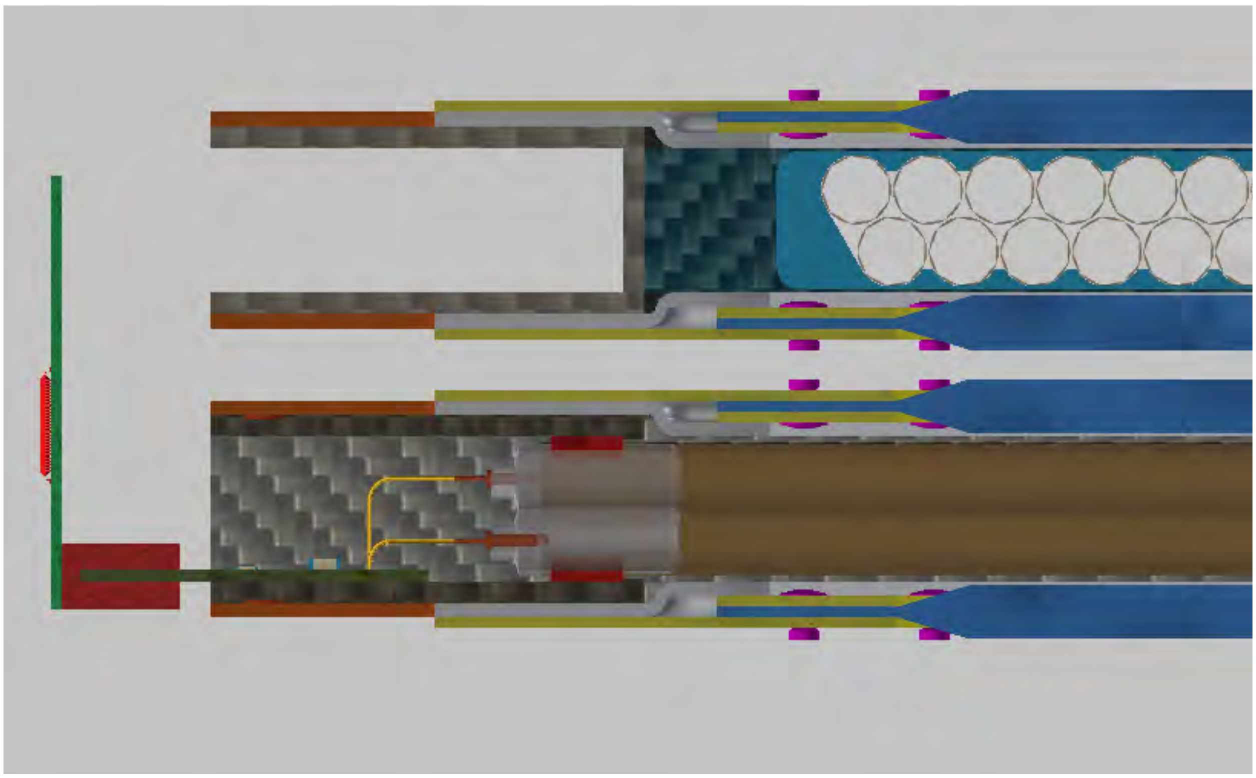

Figure 2.2: A schematic drawing of a STT module with four straw-tube planes and radiators (dark blue shading)

fig:STT_Detail

Table 2.3: Straw Tube Detector specifications

| **Item** | Specification |
|---|---|
| Straw Tube Geometry | 1cm Diameter x 3.5m Long |
| Number of Straw Tubes | 107,520 |
| Number of Straw Tubes per Plane | 336 |
| Number of Straw Tube Planes per Module | 4 |
| Number of Straw Tube Sub-Modules per Module | 6 |
| Number of Straw Tube Modules | 80 |
| Number of Straw Tube Sub-Modules | 480 |
| Length of Straw Tube Wire | 376.3 km |
| Number of Electronics Channels | 215,040 |
| Number of Modules with Radiators | 46 |
| Radiator Thickness per Module | 3.6cm |
| Radiator Mass per Module | 108 kg |
| Number of Modules with Target Planes | 34 |
| Target Geometry | 1.27cm Diameter $\times$ 3.5m long |
| Number of Targets per Plane | 275 |
| Ar Mass per Plane | 15.5 kg |
| Water Mass per Plane | 95 kg |

ab:STT_details

### 2.4.2 Radiator Targets

Radiators will be placed in the downstream STT modules and will serve as targets for both neutrino interactions and Transition Radiation (TR) production. Each STT module contains four radiators, where each radiator consists of 60 layers of 25-$\mu$m polypropylene $(C_3H_6)_n$ foils alternating with 60 sheets of 125-$\mu$m tulle fabric spacers. The mass of each radiator is $\sim$ 27 kg and the thickness is $\sim$ 9 mm. Thin graphite planes and/or carbon fiber foils can be added to some STT modules in order to have a total carbon target mass of about 0.5 t. (This is in addition to the carbon in the STT frames.) A statistical subtraction of events occurring on the pure carbon target from the ones in the polypropylene radiators will provide a measurement of antineutrino interactions on a free proton target, which can be used for flux determination and cross section measurements.

### 2.4.3 Argon, Water, and Other Nuclear Targets

Both argon and water will be implemented as target materials for neutrino interactions. The argon targets will measure neutrino interactions on the same material as the far detector, while $H_2O$ and $D_2O$ water targets can be used to determine, through subtraction, the neutrino fluxes off of "free" neutron targets. Antineutrino fluxes off of "free" proton targets can be obtained, through subtraction, from C and $CH_2$ targets. The targets will be positioned directly upstream of individual modules without radiators.

Why positioned here?

fig:STT_targets

The targets, shown in Figure 2.3, will consist of planes of 0.5-inch diameter, 3.5-m-long aluminum tubes filled either with water ($H_2O$ or $D_2O$) or with argon gas pressurized to 140 atm ($\rho = 0.233$). We will place 273 tubes in each plane, spaced 0.505-in apart. The tube wall thickness will depend on the fill material. Additional nuclear targets, such as Ca (same atomic weight as argon), C, stainless steel, and Pb, can also be used in the form of thin planes, to be positioned directly upstream of individual STT modules without radiators.

## 2.5 Electromagnetic Calorimeter

:nd-nnd-emcalo

An electromagnetic calorimeter (ECAL) will surround the tracking volume on all sides and consist of three separate pieces: Forward ECAL, Barrel ECAL, and Backward ECAL.

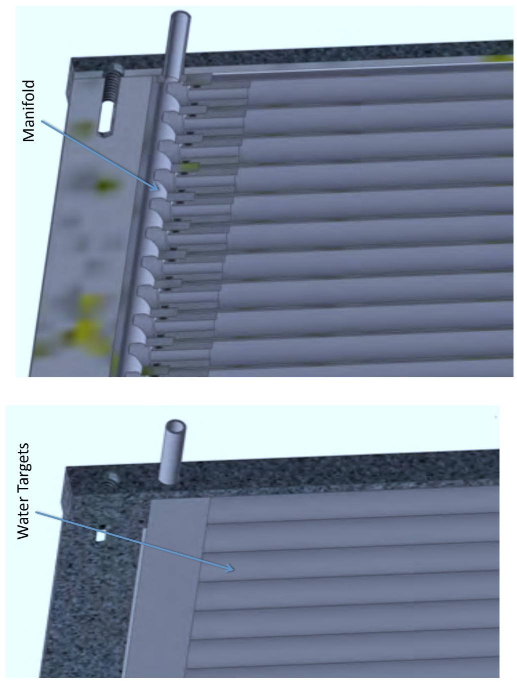


Figure 2.3: Schematic drawing of the water or pressurized-argon targets, made from 0.5-in diameter aluminum tubes fig:STT_target

There should be a figure illustrating this – or labeling on the overview image

The ECAL conceptual design consists of layers of either 1.75-mm-thick (for the forward ECAL) or 3.5-mm-thick (for the barrel and backward ECAL) lead sheets and 2.5-cm-wide by 10-mm-thick plastic scintillator bars, as shown in Figure 2.4. The scintillator layers for the Forward and Backward ECAL alternate as XYXYXY..., while the scintillator layers for the Barrel ECAL are all horizontal along the axis of the magnet. The Forward ECAL will consist of 60 layers of scintillator bars, where each bar has dimensions 3.2 m $\times$ 2.5 cm $\times$ 1 cm. The Backward ECAL will consist of 16 layers of scintillator bars, where each bar has the same dimensions, 3.2 m $\times$ 2.5 cm $\times$ 1 cm. The Barrel ECAL will also consist of 16 layers of scintillator bars, where each bar has the same dimensions, 3.2 m $\times$ 2.5 cm $\times$ 1 cm.

The lead sheets and scintillator bars will be assembled and glued together into complete modules of dimension 3.2 m $\times$ 3.2 cm $\times$ 81 cm for the Forward ECAL and 3.2 m $\times$ 3.2 cm $\times$ 27.5 cm for the Backward ECAL. For the Barrel ECAL, the module dimensions will also be 3.2 m $\times$ 3.2 cm $\times$ 27.5 cm. Two Barrel modules are placed end-to-end along the sides of the inner surface of the magnet (eight Barrel modules total) to provide full coverage of the barrel region. The total numbers of scintillator bars in the Forward, Backward, and Barrel ECAL are 7,680, 2,048, and 16,384, respectively, for a total of 26,112 bars.

The scintillator bars will be extruded with holes in the middle of each bar. The holes will then be fitted with 0.7-mm-diameter Kuraray wavelength-shifting (WLS) fibers. The fibers will be read out by SiPM (silicon photomultiplier) photosensors at each end, making the number of readout channels twice the number of scintillator bars for a total of 52,224. The total mass of scintillator is 20.9 t, the total mass of Pb is 70.8 t, and the total length of fiber is 83.6 km. Specifications for the ECAL are shown in Table 2.4. Figure 2.5 shows a side view of the ECAL (red) inside the dipole magnet, where there is very little gap between the Barrel ECAL and the Forward ECAL.

## 2.6 Dipole Magnet

The STT and ECAL modules will reside inside a 0.4-T dipole magnet for the measurement of particle momentum and charge. The magnet will have inner dimensions (inside the coils) 4.5-m wide $\times$ 4.5-m high $\times$ 8.0-m long. The magnet has four vertical Al coils, stacked horizontally, producing a horizontal magnetic field. The return yoke will be divided into two halves along the longitudinal center line to allow the magnet to be opened to service the detector inside, as shown in Figure 2.1. Each

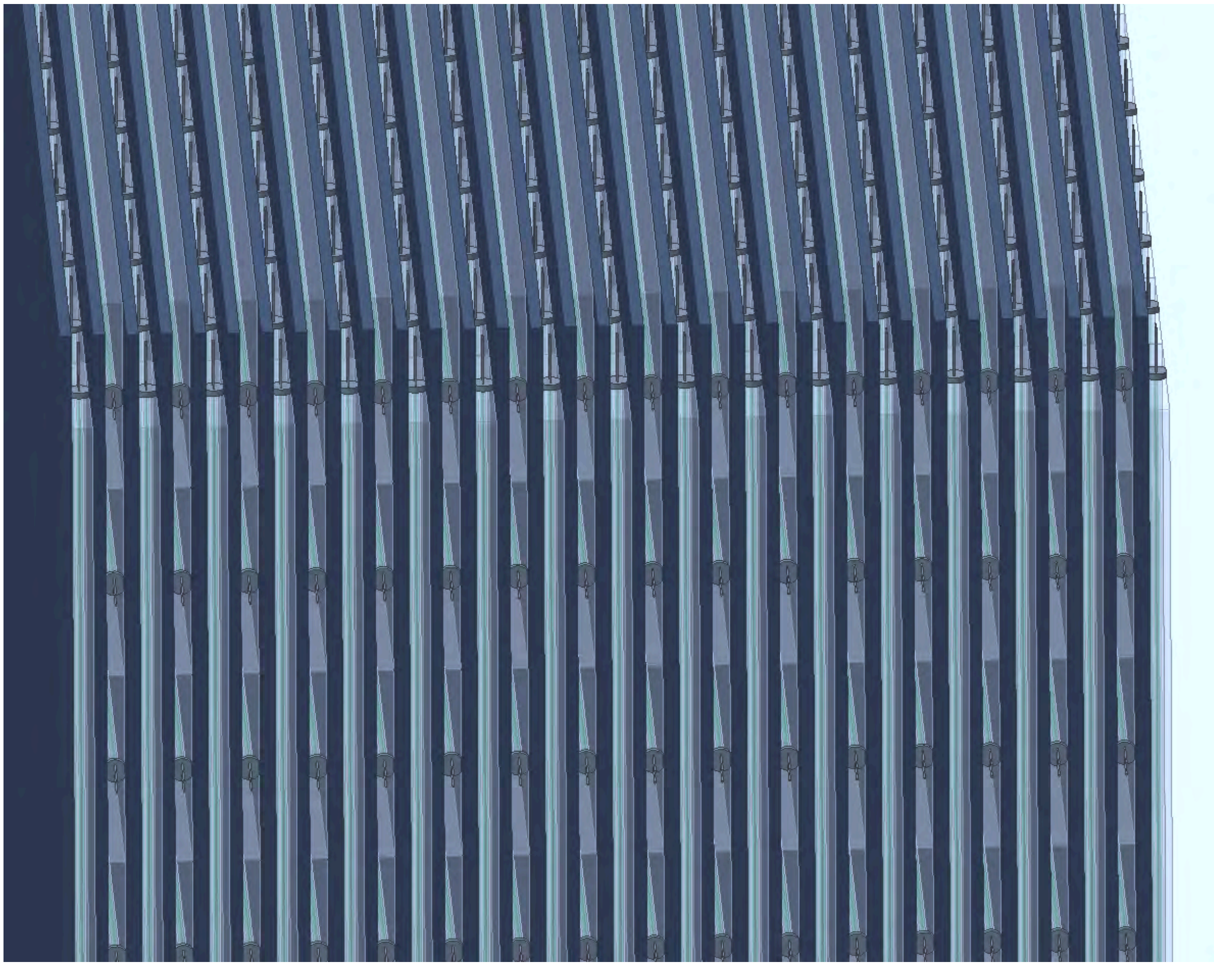

Figure 2.4: Schematic drawing of the ECAL, which is made up of alternating planes of plastic scintillator and Pb sheets.

fig:ECAL_detai

Table 2.4: ECAL specifications

| **Item** | Specification |
|---|---|
| Scintillator Bar Geometry | 3.2m $\times$ 2.5cm $\times$ 1cm |
| Number of Forward ECAL Scintillator Bars | 7680 |
| Forward ECAL Pb thickness | 1.75mm |
| Number of Forward ECAL Layers | 60 |
| Number of Forward ECAL Radiation Lengths | 20 |
| Dimensions of Forward ECAL Module | 3.2m $\times$ 3.2m $\times$ 81cm |
| Number of Barrel ECAL Scintillator Bars | 16,384 |
| Barrel ECAL Pb thickness | 3.5mm |
| Number of Barrel ECAL Layers | 16 |
| Number of Barrel ECAL Radiation Lengths | 10 |
| Number of Barrel ECAL Modules | 8 |
| Dimensions of Barrel ECAL Modules | 3.2m $\times$ 3.2m $\times$ 27.5cm |
| Number of Backward ECAL Scintillator Bars | 2048 |
| Backward ECAL Pb thickness | 3.5mm |
| Number of Backward ECAL Layers | 16 |
| Number of Backward ECAL Radiation Lengths | 10 |
| Dimensions of Backward ECAL Module | 3.2m $\times$ 3.2m $\times$ 27.5cm |
| Total Length of 0.7mm Diameter WLS Fiber | 83.6km |
| Total Number of Scintillator Bars | 26,112 |
| Total Number of Electronics Channels | 52,224 |
| Total Mass of Scintillator | 20,890 kg |
| Total Mass of Pb | 70,800kg |

tab:ECAL_specs

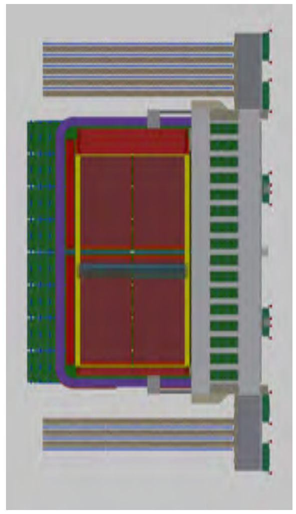

Figure 2.5: A side view of the ECAL (red) inside the dipole magnet, where there is very little gap between the Barrel ECAL and the Forward ECAL.

half yoke will be built from eight “C” (C-shaped) sections, and the thickness of the magnet steel will be 60 cm, consisting of 6 × 10-cm-thick plates. The magnet power requirement with Al coils is ∼ 2.4 MW, corresponding to 6 kA at 400 V. The water flow required for cooling is 20 l/s. The Dipole Magnet specifications are shown in Table 2.5.

The momentum resolution is dominated by multiple scattering in the STT. The momentum resolution is, therefore, given by $\delta p/p = 0.053/\sqrt{(LX_0)}B$. For B = 0.4T, L = 3m, and $X_0$ = 4m, the expected momentum resolution is ∼ 3.8%.

## 2.7 Muon Identifier

The sides and ends of the dipole magnet will be instrumented with a muon identifier detector (MuID) that will distinguish muons from hadrons by their

the muons’?

ability to penetrate the iron without showering or interacting. The MuID will consist of 432 RPC modules interspersed between 2 × 10-cm-thick steel plates

Table 2.5: Dipole Magnet specifications

| **Item** | Specification |
|---|---|
| Inner Dimensions | 4.5m x 4.5m x 8.0m |
| Magnetic Field | 0.4 T |
| Number of "C" Sections | 16 |
| Thickness of Steel in the "C" Sections | 60cm |
| Mass per "C" Section | 60 tonnes |
| Number of Coils | 4 |
| Mass per Coil | 40 tonnes |
| Magnet Current | 6 kA |
| Magnet Voltage | 400 V |
| Magnet Power Requirements | 2.4 MW |
| Water Flow for Cooling | 20 l/s |

o:Magnet_specs

there are two 10 cm thick plates or some number of 20 cm thick ones? We're missing the figure

of the dipole magnet and between 20-cm-thick steel plates at the upstream and downstream ends of the magnet. The MuID is only meant to provide identification of the muon; the muon momentum will be measured by the STT inside the magnetic field. A schematic drawing of the MuID interspersed in the magnet steel is shown in Figure 2.6. fig:FGT_MuID

The nominal dimensions of all RPC modules will be 1 m × 2 m with active areas of 96 cm × 196 cm. Each module has 256 X strips at 7.65-mm pitch and 128 Y strips at 7.5-mm pitch. The modules will be grouped into trays each containing six modules, and the trays will be sufficiently wide to allow overlapping modules. The end RPC trays have dimensions of 2 m × 6 m, and there are three trays per plane. The downstream end has five planes, corresponding to 15 trays and 90 RPC modules. The upstream end has three planes, corresponding to nine trays and 54 RPC modules. The vertical barrel-RPC trays have dimensions of 2.5 m × 4 m, 2.8 m × 4 m, and 3.1 m × 4 m for the inner, middle, and, outer planes, respectively, corresponding to 24 trays and 144 RPC modules. The horizontal barrel-RPC trays have dimensions of 2.2 m × 4 m, 2.5 m × 4 m, and 2.8 m × 4 m for the inner, middle and outer planes, respectively, corresponding to 24 trays and 144 RPC modules. Overall, there is a total of 72 trays, 432 RPC modules, and 165,888 strips and electronic channels.

The downstream MuID will contain five steel planes of overall dimensions 6 ×

$6 \times 0.2$ m$^3$ (283.5 t) and five RPC planes, while the upstream MuID will contain three steel planes (170.1 t) of dimensions $6 \times 6 \times 0.2$ m$^3$ and three RPC planes. The barrel MuID will contain 24 planes (three layers $\times$ eight sides) of RPCs. The RPCs will have a total thickness of 15 mm and a gap width of 2 mm. One possible gas mixture could be of Ar (75%), tetraflouroethane (20%), isobutane (4%), and sulphurhexaflouride (1%). A schematic drawing of an RPC is shown in Figure 2.8, while Figure 2.7 shows a schematic drawing of an end RPC tray, and Figure 2.8 shows a schematic drawing of an RPC module. MuID specifications are shown in Table 2.6.

Figure 2.6: Schematic drawing of a magnet half-assembly, showing the the MuID interspersed in the magnet steel

Table 2.6: MuID specifications

| **Item** | Specification |
|---|---|
| Number of Barrel RPC Trays of Dimension 2.2m $\times$ 4m | 8 |
| Number of Barrel RPC Trays of Dimension 2.5m $\times$ 4m | 16 |
| Number of Barrel RPC Trays of Dimension 2.8m $\times$ 4m | 16 |
| Number of Barrel RPC Trays of Dimension 3.1m $\times$ 4m | 8 |
| Number of END RPC Trays of Dimension 2m $\times$ 6m | 24 |
| Total Number of RPC Trays | 72 |
| Total Number of RPC Modules | 432 |
| Mass of Downstream Steel Planes | 283,500 kg |
| Mass of Upstream Steel Planes | 170,100 kg |
| RPC Thickness | 1.5cm |
| Number of 7.65mm Pitch X Strips per Module | 256 |
| Number of 7.5mm Pitch Y Strips per Module | 128 |
| Total Number of RPC Strips and Electronics | 165,888 |

## 2.8 FGT Instrumentation

The instrumentation includes readout electronics for the subdetectors and the slow control of the

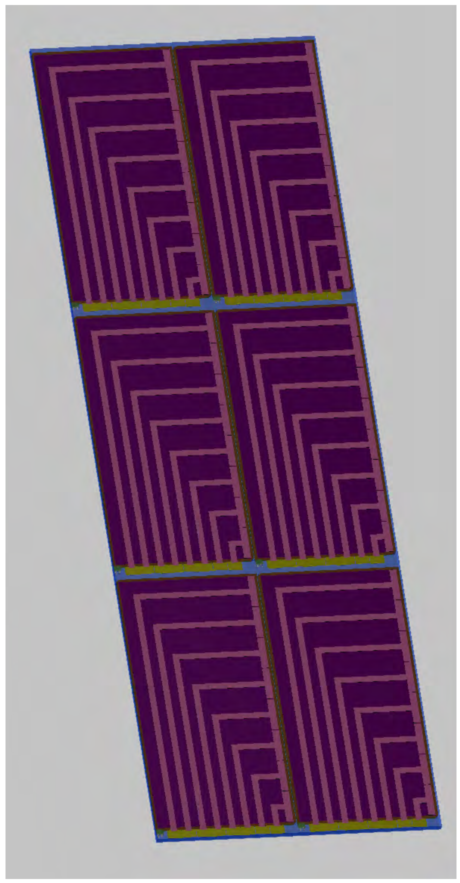

Figure 2.7: Schematic drawing of an end-RPC tray, consisting of six RPC modules of dimension 1m $\times$ 2m fig:RPC_Tray

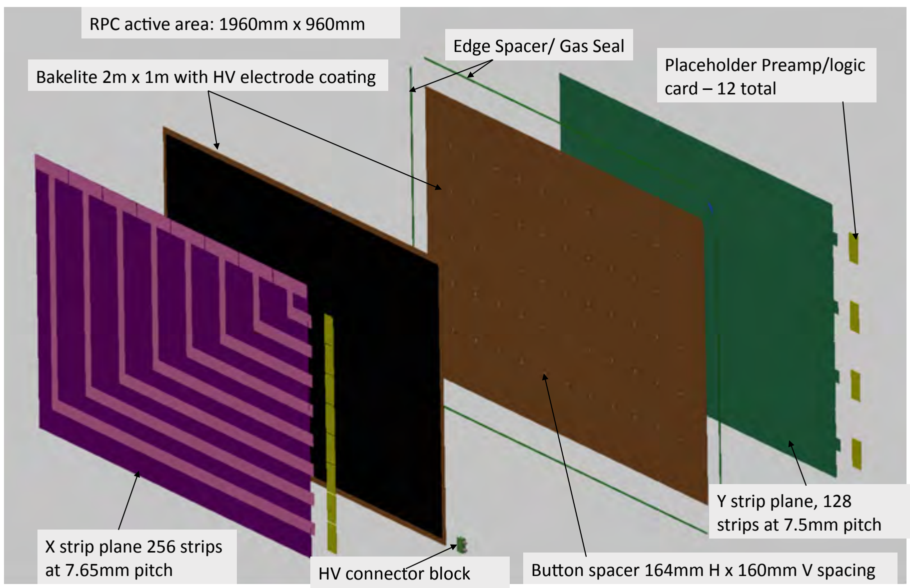


Figure 2.8: Schematic drawing of an RPC

fig:FGT_RPC

which?

subdetector, involving monitoring the humidity, temperature, gas pressure, etc.

It would be nice to have a sentence saying what slow control really means, as opposed to other kinds of control; in readout electronics, it says fast is few-to-10 ns range. Is there a range for slow?

There is considerable synergy in the information gathered in the STT, ECAL and MuID.

Is it synergy or overlap?

Both the STT and ECAL are required to measure the total charge and the time associated with a given hit. The MuID RPCs are required to provide the position and time associated with a traversing track. Similarly, the slow control of the subdetectors share many features.

features or requirements?

A brief description of the subdetector instrumentation is presented here, while Table 2.7 summarizes the number of electronics channels for each of the subdetectors.

add something here about the cooling-water flow and voltage and current monitoring; you have no information in the sections, so they should be removed.

Table 2.7: The number of electronics channels for each of the three detector systems

| Detector | Number of Electronics Channels |
|---|---|
| STT | 215,040 |
| ECAL | 52,224 |
| MuID | 165,888 |

tab:elect_ch

### 2.8.1 Readout Electronics

The electronics for the three subsystems, STT, MuID, and ECAL, are all “fast” systems, i.e., all of the signals are in the few-to-10 nanosecond range. The STT output has a roughly 10-nanosecond rise time with a total integrated charge of about of about 100 electrons per centimeter. The gain of the STT drift tubes are typically $10^4$ to $10^6$, so over a collection time interval of $\sim$ 100ns the integrated charge is $10^6$ to $10^8$ electrons. The MuId system contains Resistive Plate Chambers (RPCs) that can operate in either streamer mode or avalanche mode; the difference being that streamer mode is not proportional to the deposited charge, whereas the avalanche mode is. The rise time of the RPC signal is a few nanoseconds and charge is collected immediately; the collected charge can be large, up to 100 pC. The ECAL signals come from a SiPM that converts the light from the scintillator strips to an electronic signal. The deposited charge in the scintillator will give rise to $10^3$ to $10^5$ photoelectrons. The gain of a SiPM is $\sim 10^6$ and has a rise time of a few nanoseconds, so the total charge can be $> 100$ pC. As these three systems all have gain and are fast, it is hoped that a common electronics system may be possible.

The requirements for each system are very similar: a fast output and both an ADC and a TDC on each channel. Additionally, for the STT straw tubes it is desirable to wave-form digitize the analog signal in order to enhance the ability to separate the ionization signal from the transition radiation signal. The total channel count is 433152 channels; this is broken out into 215000 for the STT, 165000 for the MuID, and 52224 for the ECAL. Most available electronic systems from existing experiments donâĂŹt quite meet these requirements or are too expensive to implement for this channel count ($50/channel has been allocated). Recently, an interesting new ASIC development for an upgrade to the ATLAS muon system at the LHC has come out of BNL

add ref?

A schematic of the newly developed chip (VMM2) is shown in Figure VMM2 **??**. It handles 64 channels and produces both fast ADC and TDC outputs. It has been fabricated and tested and should be ready by 2017, long before it will be needed for DUNE. The VMM2 features are the following:

- front-end electronics (ASIC)
- more than 2.3 million channels total
- operation with both charge polarities
- sensing element capacitance of 10-200 pF
- charge measurement up to 2 pC at $< 1$ fC RMS
- time measurement $\sim 100$ ns at $< 1$ ns RMS
- trigger primitives, neighbor logic
- low power, programmable

The VMM2 chip will be explored as the first option for the NND readout.

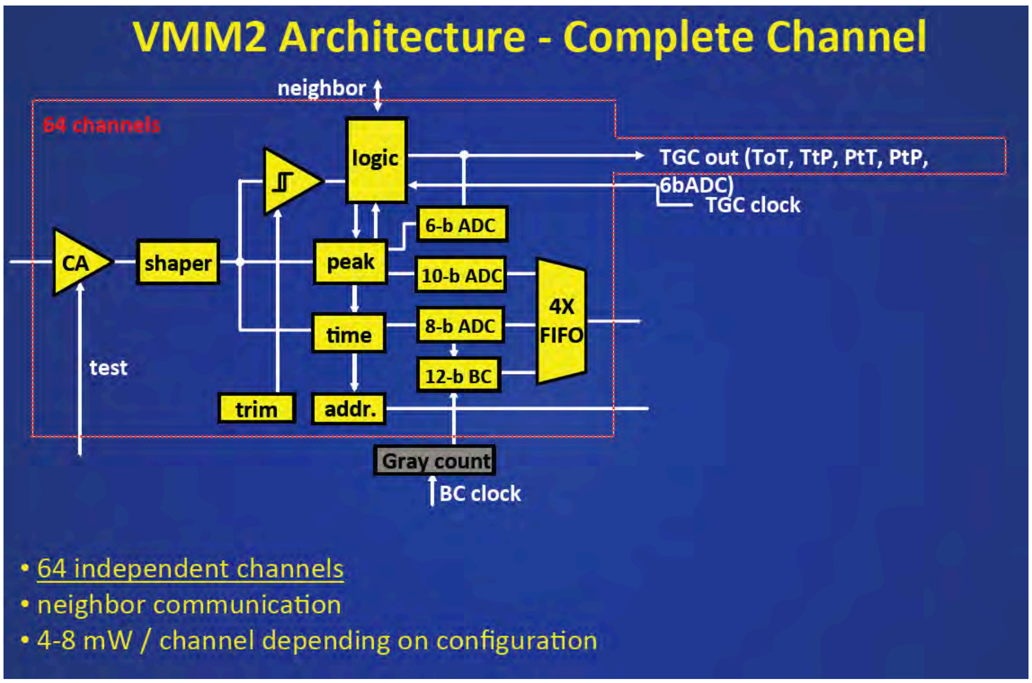


Figure 2.9: A schematic drawing of the VMM2 circuit

fig:VMM2

### 2.8.2 Data Acquisition

why isn't this called the FGT-DAQ? It's hard to know whether to use FGT or NND. FGT is easier to keep straight in your mind from NDS, that's for sure!

As the Near Neutrino Detector (NND) is part of DUNE's Near Detector System (NDS), the Near Neutrino Detector Data Acquisition system (NND-DAQ) collects raw data from each NND subsystem and connects to the (overall) Near Detector System DAQ (NDS-DAQ) via Gigabit Ethernet. This is described in Chapter 4. A block diagram of the NND-DAQ is shown in Figure 2.10. Similar to the NDS-DAQ, the NND-DAQ will mainly consist of a scalable back-end computer array, inter-connected to the individual NND subdetector DAQs via Gigabit Ethernet and specialized electronics modules for trigger processing and clock synchronization. It interfaces to the NDS Master DAQ (NDS-MDAQ), described in Section 4.1.1, for run control and global

still want 'global'?

data collection. The NND-DAQ will also have its own local run-control setup, consisting of a number of desktop workstations to allow independent local runs that include NND subdetectors only, which is useful during detector commissioning, calibration runs, stand-alone cosmic runs or other runs where the beam is stopped or not needed.

The quantity of computers required for the back-end system is highly dependent on the number of channels and expected data rates of the individual neutrino detectors. Based on T2K Near Detector DAQ experience

ref?

, one back-end computer should be able to handle approximately 3,000 channels for sustainable and continuous runs. Assuming a total of 430,000 channels for all NND subdetectors combined, about 150 back-end computers would be needed.

Trigger signals from each subdetector will be collected and pre-processed by a trigger electronics module, similar in design to the global

?

trigger or master clock modules of the NDS-DAQ design. Depending on the run mode, this module could feed local trigger decisions to the detector DAQs for data collection, or it could forward global

?

triggers from the NDS-DAQ or higher levels to the neutrino detector DAQs. A slave-clock electronics module, similar to the master-clock module in the NDS-DAQ, distributes clock- and time-synchronization signals from the NDS-DAQ to all NND subdetectors.

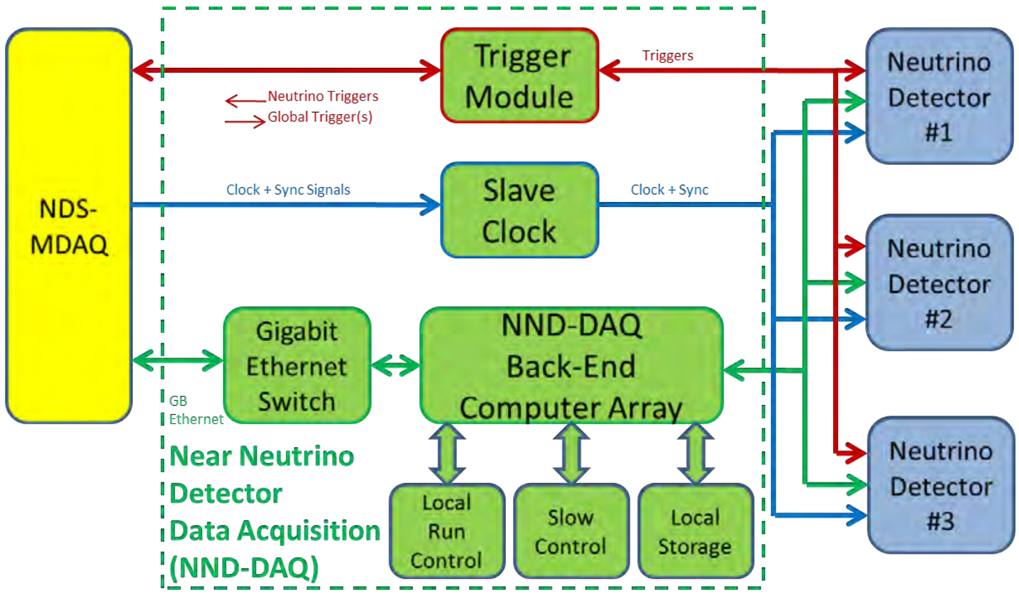


Figure 2.10: A block diagram of the Near Neutrino Detector DAQ (NND-DAQ) fig:DAQ_NND

### 2.8.3 Humidity and Temperature Monitoring

Humidity is inimical

‘detrimental’ is a more common word; better?

to all the FGT subdetectors. To maintain a low level of humidity and to maintain a desired temperature, both STT and ECAL subdetectors will have dry nitrogen circulating within their outer layers. A similar arrangement might be made for the

RPCs, as well. Regarding the magnets, magnet coils are cooled by water, while the magnet yokes are instrumented with RPCs

that must remain dry?

. Thus, a continuous control of humidity in all these detectors is needed. Just as for humidity, temperature must be continuously monitored in all of the subdetectors.

you don't say why.

### 2.8.4 Gas Leak Monitoring in the STT and MuID

The STT will employ Xe gas, which is expensive and, hence, will be recirculated.

Other uses of gas?

Gas leaks need to be monitored in the STT and MuID, particularly for the Xe. The requirement for leaks is less stringent for the RPC.

I'd have to go back and figure out what RPCs have to do with gas; you should add sentence here

### 2.8.5 Cooling-Water Flow Monitoring in the Magnet

The water flow (pressure gradient) must be continuously monitored.

Add more or remove section, I'd say and . AH

### 2.8.6 Monitoring Voltage and Current

All power sources instrumenting the FGT and its readout need to be monitored for appropriate voltage and current.

Add more or remove section, I'd say and . AH