SoLID pre-R&D Plan

SoLID Collaboration

January 21, 2020

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1 Summary and Responsibility

1.1 Summary

We present here a pre-R&D plan for the SoLID (**So**lenoidal **L**arge **I**ntensity **D**evice) spectrometer. The goal is to mitigate the primary technical, schedule and cost risks in advance of the project start. These risks are due to the large scale of the project, as well as the requirement for operation at high luminosity. The time duration for the planned activities is 1.5 years. The pre-R&D plan is on the high rate electronic and DAQ system (Section 2) and the gas Cherenkov detectors (Section 3), which are the two systems with potential risks identified.

For the DAQ system, there are two main issues. First, the initially proposed readout chip for the GEM readout in the earlier version of the SoLID pre-CDR is obsolete and a new modern chip has been identified as a suitable replacement. The pre-R&D tests will allow us to be sure the new chip based readout system satisfy the SoLID DAQ requirements. Second, we need a small-scale test stand of the DAQ system to study the DAQ system performance and support the detector tests in order to find out if they will be able to meet the demanding requirements in the high-rate environment. This will impact the trigger and readout of the major systems, including the gas Cherenkovs (light and heavy), calorimeter, and time-of-flight detectors.

The gas Cherenkov detectors (Section 3) are critical for creating efficient triggers and providing particle identification in the high-rate environment of SoLID. The SoLID light gas and heavy gas Cherenkovs designs use square shaped photosensors known as multi-anode photomultiplier tubes (MaPMTs) in order to cover a large area through tiling. The high level of pixelization of the these photo sensors can potentially help reduce backgrounds. We plan to build and test a telescopic Cherenkov device to verify that the proposed Cherenkov detectors can reach the desired performance in the high-rate environment. The available granularity of the photosensors can provide an improved performance in rejecting background in the harsh environment of high luminosity.

The pre-R&D-plan budget is summarized in Table 1 (breakdown in terms of sub-projects) and Table 2 (breakdown for different groups). The details are described in the following sections as noted above.

Item	mat.($K)	per. ($K)	total ($K)
DAQ	227.3	372.7	600
Cerenkov counters	210	240	450
Sum	437.3	567.7	1050

Table 1: Summary of budgeted materials and personnel for different projects

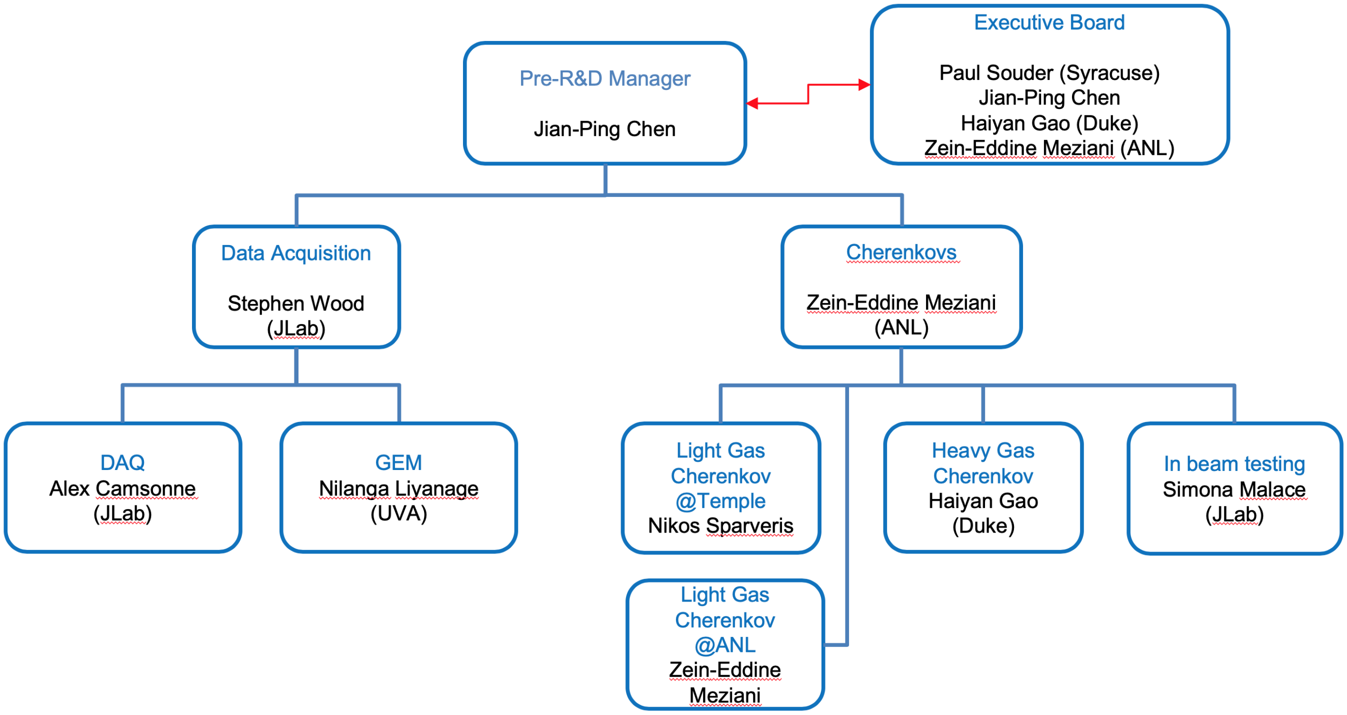

Figure 1: Management/oversight organization of pre-R&D activites.

Item	mat. ($K)	per. ($K)	total ($K)
JLab	227.3	372.7	600
Temple	126.3	121.5	247.8
Duke	74.3	118.5	192.8
ANL	9.4	0	9.4
Sum	437.3	567.7	1050

Table 2: Summary of budgeted materials and personnel for different groups

1.2 Responsibility

Jian-Ping Chen (JLab) will take the overall responsibility (Fig. 1) of pre-R&D activities with input from the SoLID Executive Board (Paul Souder, Jian-Ping Chen, Haiyan Gao, and Zein-Eddine Meziani). Stephen Wood (JLab) and Zein-Eddine Meziani (ANL) will be responsible for the main individual components of the plan, data acquisition and high rate Multi-anode PMT Cherenkov detector tests, respectively.

Within the data acquisition activities, Nilanga Liyanage (UVA) will be responsible for the GEM detector related activities while Alex Camsonne (JLab) will be responsible for other DAQ activities (timing chip tests, MAROC chip tests and DAQ prototype/trigger activities.)

Nikos Sparveris (Temple) and Zein-Eddine Meziani will be responsible for Light Gas Cherenkov activities at Temple University and ANL respectively. Haiyan Gao will be responsible for Heavy Gas Cherenkov work at Duke University. In-beam tests of Cherenkov detectors at JLab will be coordinated by Simona Malace (JLab).

Quarterly reports tracking costs and milestones will be prepared. The quarterly reports for Data Acquisition will be prepared by Stephen Wood, reviewed by Jian-Ping Chen, and sent to Allison Lung at JLab. Quarterly reports for the Cerenkov tests will be prepared by Zein-Eddine and submitted to Jamie Hayley at ANL. The combined quarterly reports will be reviewed by Jian-ping Chen and checked by the executive board and summaries will be submitted to Gulshan Rai at the DOE. Progress on the SBIR activities will also be sent to Michelle Shinn at the DOE for information. Account Management at JLab and ANL will release contingency funds and respond to requests to reallocate funds if necessary.

The SoLID executive board will form an outside Committee to review this pre-R&D plan. The committee will consist of three members that are outside SoLID collaboration: one from LBL or BNL, one from ANL, and one from JLab. The review will take place in the spring of 2020.

2 DAQ

2.1 Overview

The requirements for the SoLID DAQ exceed those of any previous experiment at JLab. The SIDIS experiment has an expected trigger rate on the order of 100 kHz and a total data rate of 3 Gb/s. In addition, simulations performed for the SoLID setup have indicated that the background hit rates at the GEM trackers could be as high as 500 KHz/cm^2 in the PVDIS case. These rates place severe demands on the trigger and event readout electronics. While the hardware designs should meet these specifications, some firmware developments are required to achieve the level of performance needed. This will entail thorough testing and optimization of the system.

The goals of Pre-R&D to mitigate technical and cost risks that are related to the DAQ are as follows:

- The GEM tracking detectors for SoLID have about 187,000 readout channels [1]. The baseline proposal is to fully instrument the GEM detectors with the BNL VMM3 chip [2], a promising modern technology.
  - Detector simulations indicate that a GEM readout system based on the VMM3 chip will meet the needs of SoLID at the expected trigger and background rates, 100 kHz, and 500 kHz/cm^2 respectively. However, this relies on the use of the VMM3 chip in a fast readout mode that has not been extensively used. Testing the VMM chip in this fast readout mode will mitigate the technical risk of the GEM readout.
  - The SBS program at JLab [3] uses a large number of GEM detectors, instrumented with the APV25 chip readout [4] by MPD (Multi-Purpose Digitizer) boards. While it it is preferable to instrument the SoLID GEMs with a single readout technology, the cost of SoLID could be reduced by reusing the SBS GEM electronics to instrument a portion of SoLID. We will confirm that the MPD/APV25 electronics are capable of trigger rates of at least 100 kHz as needed by SoLID, and will develop firmware, if required to achieve this goal, to determine if this is a path towards reducing costs. This work will be highly synergistic with the ongoing high rate DAQ tests for the SBS project.
- The second goal of DAQ pre-R&D is to establish a prototype DAQ system to investigate various readout technologies and trigger issues, as well as to carry out tests of critical detectors under realistic background rates.

- The proposed DAQ system is based on the FADC250 [5] and other existing JLab designed modules as shown in Figure 3. We will build a DAQ system and develop the firmware to prototype trigger and readout methods. This work will include the development of fast readout over the VXS back plane and clustering algorithms for the calorimeter. The limits of the system in terms of trigger rates and data flow will be determined with bench tests.
- The time-of-flight particle ID of SoLID requires a timing resolution of 150 ps for the SPD (scintillator) detectors. We will compare the performance of the readout with flash ADC's to that of the AARDVARC [6] sampling chip to evaluate which technology should be adopted.
- The default Cherenkov detector readout and trigger assumes that the pixels of each MaPMT (multi-anode Photomultiplier Tube) are summed together. We will also test the capabilities of the MAROC readout chip [7] to balance pixel gain and supply hit information for the individual pixels. We will determine if this technology is suitable for SoLID.

2.2 GEM Tracker Readout

The SoLID GEM tracker will have about 187,000 readout channels. The large event size and volume of data (several Gbyte/s) from these detectors operating at the high rates could be the limiting factor on the highest possible trigger rate, and hence the data collection rate, for a given experiment; the trigger rate for the SIDIS experiments of SoLID needs to be at least $\sim$ 100 kHz. This trigger rate is unprecedented for high volume GEM tracker systems (for example, the trigger rate for SBS experiments is expected to be not more than 5 kHz). Careful estimates based on on available bandwidth limitations, clock speeds of the planed electronics, and evidence from limited scope test setups from elsewhere seem to indicate that a trigger rate of 100 kHz will be feasible under SoLID conditions. However, there could be many unforeseen issues and complications that could arise under real running conditions which could lower this rate limit. One of the highest priorities for the pre-R&D program is to ensure that the proposed readout electronics are able to operate at the required trigger rate of 100 kHz under realistic conditions. This will be established in the pre-R&D by (a) ensuring that feasibility large volume data transfer rates given the actual (as opposed to specified) bandwidth limitations under close to realistic conditions, and (b) developing techniques for real-time (FPGA level) hardware based suppression of information from channels without any data (zero suppression) and from channels with hits which do not correlate with the trigger time (out-of-time suppression). Some of the ongoing work related to this carried out to meet the SBS running conditions is documented in detail in [8]

2.2.1 VMM

The VMM chip was developed at BNL for the ATLAS large Micromegas Muon Chamber Upgrade and is an excellent candidate for large area Micro Pattern Gaseous Detectors such as GEM. The VMM is a rad-hard chip with 64 channels with an embedded ADC for each channel. This chip is especially suited for high rate applications such as the SoLID tracking detectors. The VMM has an adjustable shaping time which can be set to be as low as 25 ns. In the standard (slower) readout mode, the ADC provides 10-bit resolution, while in the faster, direct readout mode, the ADC resolution is limited to 6-bits. The fast direct readout mode has a very short circuit reset time which could be as low as 50 ns following processing of a signal. Given the high single rates of SoLID experiments, the VMM would need to be operated in this direct readout mode to ensure that the deadtime per channel is not becoming an issue.

Another possible concern with the VMM chip is that it does not allow for multi-sample readout. Following a signal that reaches above a pre-set threshold amplitude, the VMM reports only two pieces of information, the signal time and the amplitude. As such, the VMM does not allow pulse-shape fitting to suppress out-of-time background hits. However, simulations of the direct readout mode operation of VMM seem to indicate that it will be able to handle the expected high rates of SoLID.

The VMM chip has already been adapted by the CERN RD-51 collaboration for Micro-Pattern Gas Detectors to replace the APV-25 chip. The electronics working group of the RD-51 collaboration has already created a new version of its Scalable Readout System (SRS) [9] based on the VMM chip. The UVa (Liyanage) group, which has extensive expertise operating the APV based SRS readout, is currently in the process of acquiring a 500 channel VMM-SRS system. However, the VMM-SRS system is configured to operate in the standard readout mode of the chip; it does not allow testing the chip in the direct readout mode needed by SoLID. An electronics test stand with the VMM Chip configured to run in the direct readout mode is essential for evaluating and confirming the suitability of the VMM chip for SoLID.

Pre R&D plan for the VMM test-setup

- As part of this pre R&D. we are planning to procure a VMM3 evaluation board to develop the direct readout mode and to test it in high background rates comparable to what is expected under SoLID conditions.
- In parallel, we will be using the VMM-SRS electronics to test the maximum trigger and data rates achievable.
- We will setup a contract with Gianluigi De Geronimo, the former BNL electronics expert who designed the VMM3 chip, through the consulting company DG CIRCUITS,

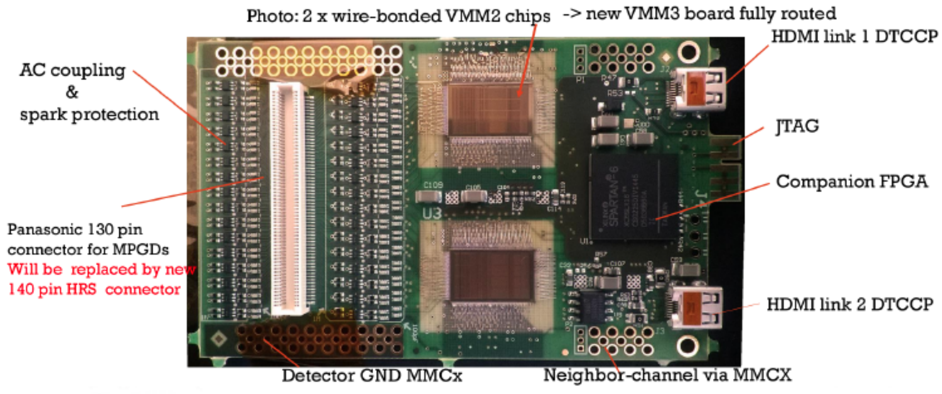

Figure 2: The VMM chip based CERN RD-51 SRS readout card. The previous generations of this readout card were based on the APV-25 chip.

to assist with development of the direct readout mode. He is also Adjunct professor at Stony Brook University and Adjunct Research Scientist with the University of Michigan.

- Once this direct mode is implemented, the test readout channels will be evaluated as detailed below.

2.2.2 Testing plan and deliverables for the VMM readout system

Objectives of this test plan are to:

- determine maximum trigger rate achievable
- estimate the effects of high background on VMM3 data

These objectives will be achieved using the following plan

- **Bench tests in the electronics shop at Jefferson lab:** Once the VMM evaluation boards are fabricated and ready for testing, they will be bench tested using a pulsar trigger, at different trigger rates ranging from very low (around 100 Hz) up to 150 kHz. This test is aimed at determining the maximum trigger rate achievable from VMM under a full load. These tests will be arranged as follows:
  - The cards will be connected to a dummy GEM detector, an old prototype GEM detector with 100 cm long readout strips with a small stereo angle of 12° from the UVa group. This readout strip length and structure is very close to what is proposed for SoLID GEMs; this is important to ensure that the input capacitance

seen by the VMM chip is similar to what is expected in real SoLID conditions. In this case the GEM detector will be powered up to a sub-threshold high voltage. Although the detector will not be generating good signals of its own, it will be generating baseline intrinsic noise as expected from a SoLID GEM.

- This baseline noise will be read in from all readout channels (a) without any zero suppression, and (b) under partial zero suppression to allow different levels of occupancy (for example, ranging from a very low 5% to a very high 90%). This is to determine the maximum trigger rate of the VMM readout under a full load of 100% and as a function of different levels of occupancy; the GEM detector occupancy levels for SoLID experiments are estimated to vary from a few percent in SIDIS and J/ψ to up to 50% in PVDIS.
- Electronically generated "GEM-like" signals will be injected into a few readout channels. These signals will be generated such that their strength and the time structure are similar to what would be expected for a MIP from a SoLID GEM under operating conditions.
- It is extremely critical that these signals are generated completely randomized in time with respect to the trigger signal to simulate JLab conditions, as opposed to collider experimental setups at CERN. (Incidentally, this is the main reason that this part of the pre R&D is extremely critical and we can not simply rely on the R&D work done at BNL for running fast VMM readouts in the ATLAS experiment at CERN; it is much easier to achieve high rate readout where the trigger signal is correlated with detector signals than to achieve similar rate capabilities in fixed target settings where the trigger signal is not correlated with the detector signals)
- The data from this test will be analyzed to establish the efficiency and the accuracy of the VMM readout as a function of the trigger rate. In this case the efficiency and accuracy could be extracted easily from the analyzed data because the input rate and the input strip locations of the injected signals are known.

- **High trigger rate, high background rate tests of the VMM readout with a powered GEM detector:** This test will establish the feasibility of running the VMM readout at the highest background rates expected under SoLID conditions, while being able to extract the signal hits with acceptable accuracy and efficiency. These tests will be arranged as follows:
  - These tests will be carried out in the UVa X-ray test facility using a prototype operational GEM module (built as part of the EIC detector R&D program at UVa) with similar features to the proposed SoLID GEMs; a detailed description of the UVa X-ray test facility and the EIC prototype GEM module is provided in

appendix A. The X-ray test facility provides background rates, and occupancies in excess of the values predicted by the SoLID simulations.

- The GEM modules will be fully operational with the high voltage and the gain set to achieve a 90% efficiency at low rates.
- As shown in fig 13, a ^{90}Sr β-source will be mounted close to the GEM creating a localized patch of electron hit illumination on the GEM.
- A small scintillator located behind the GEM triggers on electrons from the ^{90}Sr source making it through the GEM; with the current setup, this give a localized trigger rate of approximately 30 Hz due to electrons from the source.
- A run with the X-ray off and the low rate trigger from the ^{90}Sr source alone will be used to establish the baseline efficiency and position distribution due to the events from the source.
- A second random trigger at different rates up to 100 kHz will be mixed into the ^{90}Sr; then at each random trigger rate, the X-ray source will be run at different luminosities to generate random hit rates up to what is expected under SoLID conditions. Data will be collected at each trigger rate for each X-ray illumination.
- The data from this test will be analyzed to establish the efficiency and the accuracy of the data collected using VMM readout as a function of the trigger rate and the occupancy level. In this case the efficiency and accuracy for the electron tracks from the ^{90}Sr source relative to the low rate baseline run.

2.2.3 APV25

The Super Bigbite Spectrometer program at JLab uses over 60 large area GEM detectors with approximately 165,000 readout channels. These GEMs are instrumented with APV25 readout chips which interface with MPD (Multi-Purpose Digitizer) [3] boards. The APV25 chip was developed by the Imperial College, London for the CMS collaboration for the readout of tracking detectors; the MPD boards were developed by the electronics group at INFN-Genova for the SBS project. This readout system will be available for reuse by SoLID if needed as a backup or an alternate plan to reduce costs. In this case some fraction of the SoLID GEMs could be instrumented with this APV25 based system.

The APV25 is a multiplexing chip of 128 channels, which gives an intrinsic readout time of 3.5 μs (40 MHz clock and 141 signal transferred for each trigger) for one sample, limiting the trigger rate to a theoretical 280 KHz. In practice we could expect it to be as low as 100 KHz. While this limit is not an issue for PVDIS, this will restrict SIDIS and J/ψ experiments to one sample per hit with a trigger rate of 100 KHz, while several samples per hit is desired (increasing the number of samples from one decreases the maximum trigger rate proportionally). While the APV25 appears to be suitable for the relatively low rate back tracking layers of SoLID, full system tests using the APV25 with the MPD need to be performed to confirm trigger and data rate capabilities. Some firmware development may be required to achieve the performance required for SoLID. Some of these firmware developments are currently ongoing as part of the preparations of the APV25 based DAQ for SBS experiments. The work needed to achieve the SoLID requirements is highly synergistic with this ongoing work, while much more demanding at the same time with the 100 kHz trigger rate needed for SoLID compared to the 5-20 kHz trigger rates required for SBS.

Pre R&D plan for the APV test-setup

- Continue and extend the ongoing APV-25 DAQ for SBS in the area of real-time (FPGA level) hardware based suppression of background and noise related information from the online data stream.
- Evaluate the use of newly available more modern and more powerful versions of data processing, data transfer and data storage hardware as compared to the versions used for the SBS project to reach 100 kHz trigger level needed for SoLID.

2.3 Data Acquisition Test Stand

2.3.1 Data Acquisition Prototype

The goal of the pre-R&D is to develop, prototype the system, and finalize the design to ensure that the required performance can be achieved and address unforeseen issues that could arise. We will start by developing a prototype one-crate DAQ system correspond- ing to one sector of the PVDIS experiment (1/30th of the whole detector) to validate the rate capability and measure performance and dead time of a sys- tem with Flash ADCs (FADC) and GEM tracker readout. This DAQ prototype will also be used to test the calorimeter trigger which will be based on the sum of 7 adjacent calorimeter blocks. Implementation of the fast readout of the FADC through the VXS backplane will allow read out the data much faster than with the regular VME backplane as modules are read out in parallel (16 x 125 MB/s vs 200 MB/s). Only data belonging to the high energy cluster will be transferred which will reduce the number of channel firing due to low energy background as shown in Fig. 3 A key aspect of this part is that for the calorimeter, data from adjacent sectors (and from a different crate) is required to be incorporated into the trigger and data readout. For the SIDIS and J/ψ experiments, we will develop a slightly different system where one DAQ is used rather than taking data primarily from one crate. The system will be bench tested with pulsers and high-rate sources that simulate the expected rates from both good triggers and backgrounds. For the PVDIS experiment, we expect rates up to 2 MHz per Cherenkov

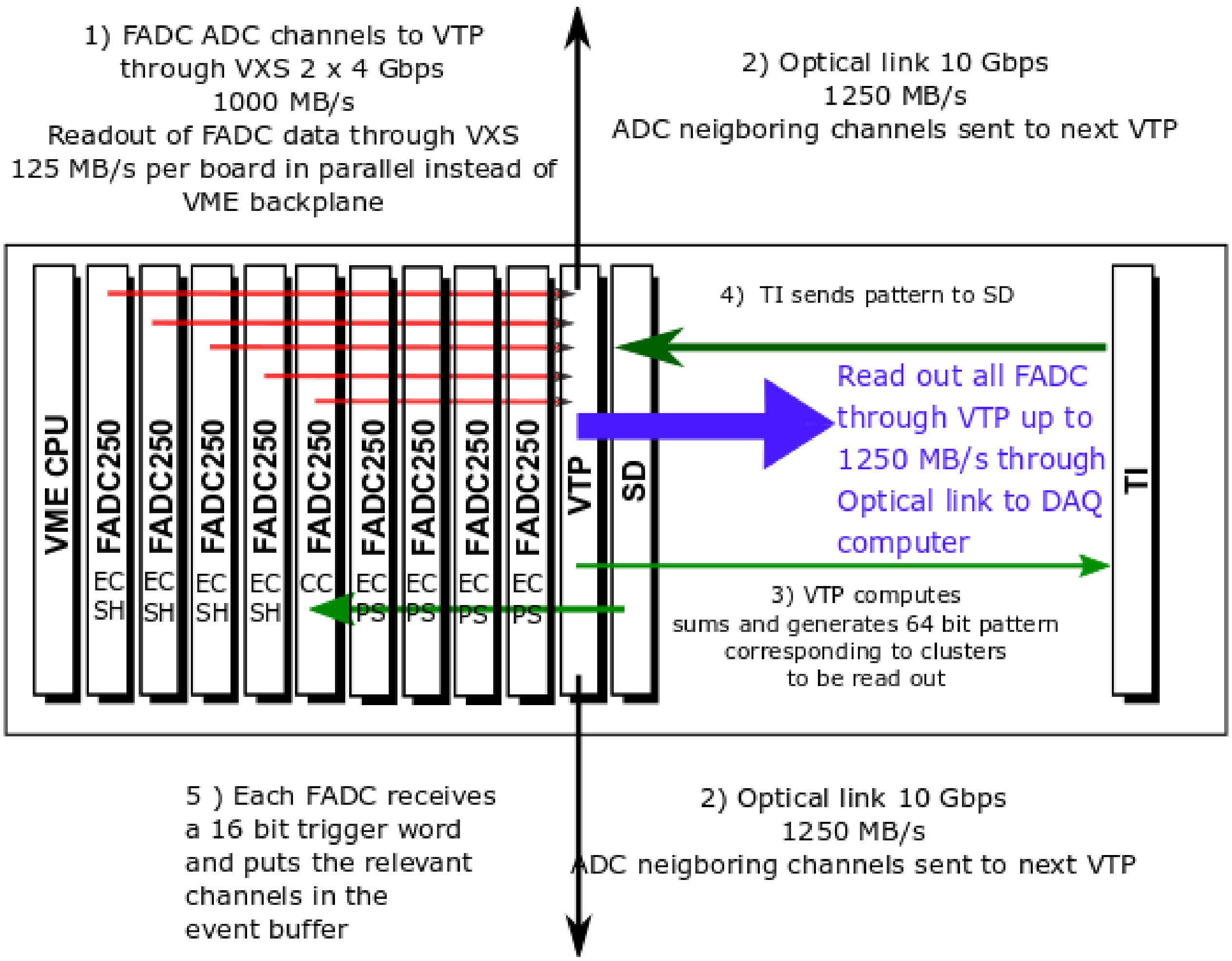

Figure 3: VXS crate module configuration for PVDIS

channel and up to 900 kHz in the calorimeter and up to 9 MHz in the pre-shower. The rates in the GEMs will reach up to 5 MHz. For the SIDIS and J/ψ one single DAQ will be used and we want to make sure it can handle a 100 kHZ trigger rate. We expect the DAQ can achieve a trigger rate higher than 100 Khz. Additional detectors such as the heavy gas Cherenkov (HGC) will have rates up to 4 MHz and the scintillator pad detector (SPD) up to 4.5 MHz. Particle identification needs to be demonstrated with the current detector granularity. Efficiently rejecting the background noise and events online is thus crucial to meet the needed trigger rate and reduce the data footprint of the experiment. Finally, algorithms for data reduction could be deployed in the electronic's FPGAs to determine data reduction factors under realistic conditions. Based on these tests, we can make a realistic estimation of the effect of dead-time and pile-up in the experiments. The accidental rate is linked to the coincidence window between detectors. In the pre-CDR a conservative coincidence window of 30 ns was used. We plan to study if this can be reduced further using high resolution trigger information from the FADC and other detectors. Such a trigger is feasible as the intrinsic timing resolution of detectors is at the nanosecond level and offsets can be digitally corrected. Finally, the system will also allow data taking with actual detectors in beam as discussed in Section 2.6.2 to study performance, the effects of background , and how effectively the backgrounds can be rejected. Beam tests with this DAQ will also allow validation of simulation results.

2.3.2 Time of flight readout

For the SIDIS experiment, high resolution time of flight (TOF) measurements will be used for particle identification. The scintillators used for photon rejection will also be used for TOF with a timing resolution is expected to reach 150 ps or better. To reach such resolutions in a high background environment the 4 ns sampling FADC might not be sufficient. A higher sampling rate chip such as SAMPIC, DRS4 or PSEC4 might be needed to reach the required timing resolution. Those chips, which use the analog sampling concept, currently have a large deadtime due to the multiplexing of the samples when readout for each trigger.

The SoLID measurement for the SPD will be more difficult than in the calorimeter application since we will be looking for minimum ionizing particles which can have lower amplitude than the background. New multilevel chips are being developed which will allow digitization of signals to continue while data is being readout. Our first candidate is the recently developed AARDVARC chip by NALU Scientific. An evaluation board for the AARDVARC will be procured to test timing resolution, rate capabilities and actual timing resolution in beam.

System	Cost ($)	Number	Total
VXS crate for DAQ modules	15,000	2	30,000
VTP - Module for triggering and data movement	10,000	2	20,000
SSP - Subsystem Processor for data movement and proceesing	6,500	1	6,500
TI - Trigger Interface	3,000	2	6,000
SD - Signal Distribution card	2,500	2	5,000
FADC trigger distribution card	2,000	2	4,000
VME CPU	4,500	2	9,000
Trigger Supervisor	3,500	1	3,500
Hardware components for VMM readout test stand	25,000	1	25,000
APV25 GEM system	23,000	1	23,000
Cables/patch	400	160	64,000
Optical transceivers	50	12	600
Optical fibers	100	20	2,000
MAROC eval board	23,000	1	23,000
AARDVARC eval board	10,000	1	10,000
Optical transceivers	50	20	600
Total			210,600
Overhead			16,700
Total request			227,300

Table 3: Material budget

2.3.3 Gas Cherenkov Readout

The Cherenkov detectors will be instrumented with 64 pixel multi-anode PMTs (MaPMT). The default readout is summing all 64 pixels with a simple sum board into a single FADC channel. We will investigate the MAROC chip for the Cherenkov detector. The MAROC chip features a analog sum which can be connected to a JLab FADC at the same time. We plan to test both readout options and the work will be coordinated with the Cherenkov pre-R&D activities as discussed in section 3.3.

2.4 Schedule and Personnel

In the first year of pre-R&D we plan to implement the calorimeter cluster trigger, FADC fast readout through VXS and FADC cluster readout as well as evaluate the performance of the new readout. GEM performance for the different chips will be studied allowing the evaluation of the deadtime expected from the GEM readout for PVDIS and SIDIS. We will also have a first prototype of the Cherenkov readout with the detector to ensure that the timing response and signal to noise ratio are adequate. Data with beam will also be taken for the calorimeter and the Cherenkov to have a realistic background sample to test data reduction algorithms and their performance. In the next 6 months after year 1 the modules to populate a second crate are requested so the interface between two sectors for PVDIS can be finalized and studied. This will allow us to study the global deadtime of the full system in the PVDIS configuration. These setups will also allow the taking of beam data with the full detector setup to validate rates obtained from simulation and test data reduction algorithms. The high resolution timing chip AARDVARC will be procured to evaluate trigger rate capability and achievable resolution.

The personnel needed for the Pre-R&D work are summarized in Table 4. We have hired a postdoc to carry out the work through UVA, the remaining work will be shared with the Hall A postdoc.

In addition to JLab labor, we plan to contract the VMM3 designer Dr. De Geronimo of the consulting company DG CIRCUITS, who is available to help develop the VMM3 direct readout mode. With overhead, 78.25 K$ is budgeted.

The budget summary of materials and personnel for DAQ is listed in Table 5.

2.5 JLab Contribution

As the SoLID DAQ is based on the JLab pipelined electronics developed for 12 GeV, we can take advantage of the data acquisition and fast electronics groups' existing work. For GEM readout, JLab is already building a test stand with about $50K of hardware to evaluate the SAMPA chip for TDIS, and has JLab staff support to evaluate the performance of the readout using this system. SoLID will use the same test setup with additional hardware to evaluate different high speed DAQ options. JLab physics division will continue to contribute to the SoLID Pre-R&D effort by providing the staff resources to help carry out the different tasks listed in Table 4.

2.6 Timeline and milestones

The timeline for data acquisition Pre-R&D activities is shown in figure 5. The major milestones are in the subsections below.

2.6.1 GEM testing milestones

VMM3 VMM3 will study the behavior of the VMM3 in high background and the maximum trigger rate that could be achieved.

- Milestone A1 April 1st 2020 : finish development of VMM3 direct readout

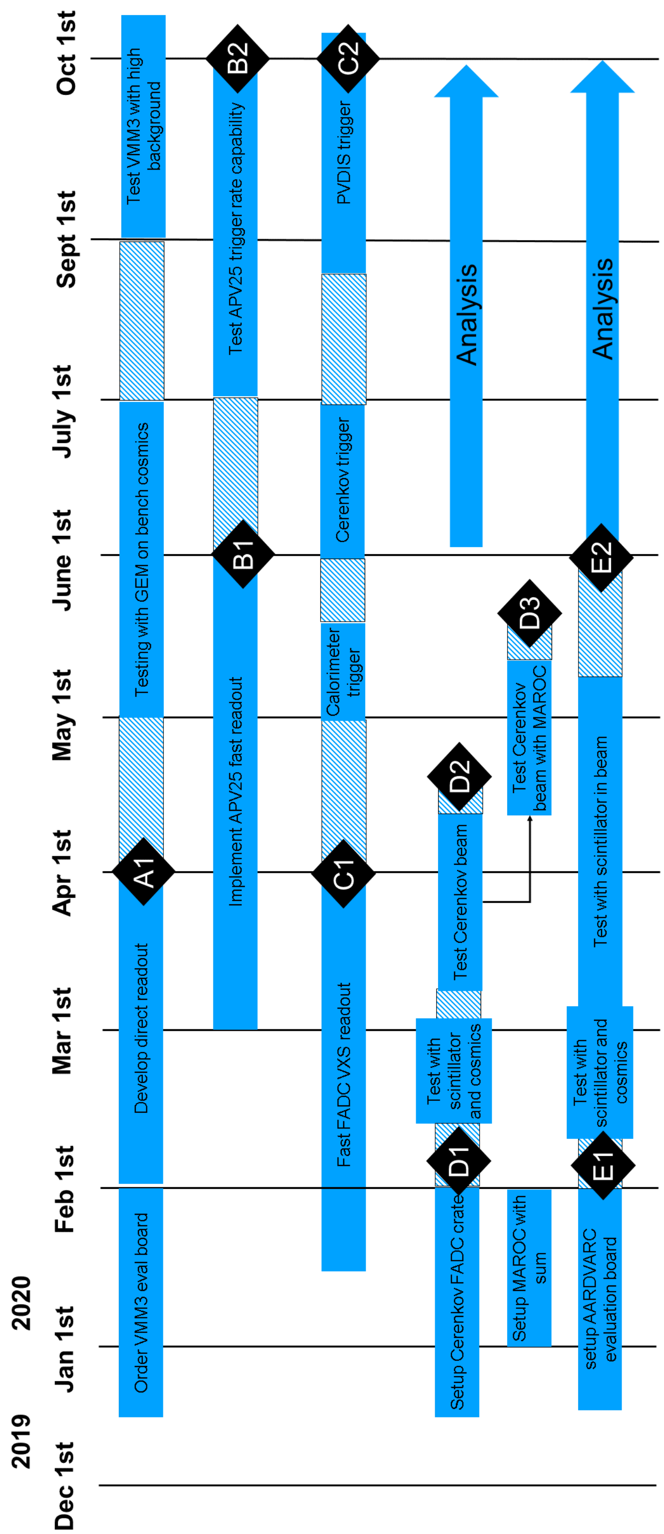

Figure 4: Timeline for data acquisition for first year of pre-R&D activities. Solid boxes indicate major activities and striped boxes represent float.

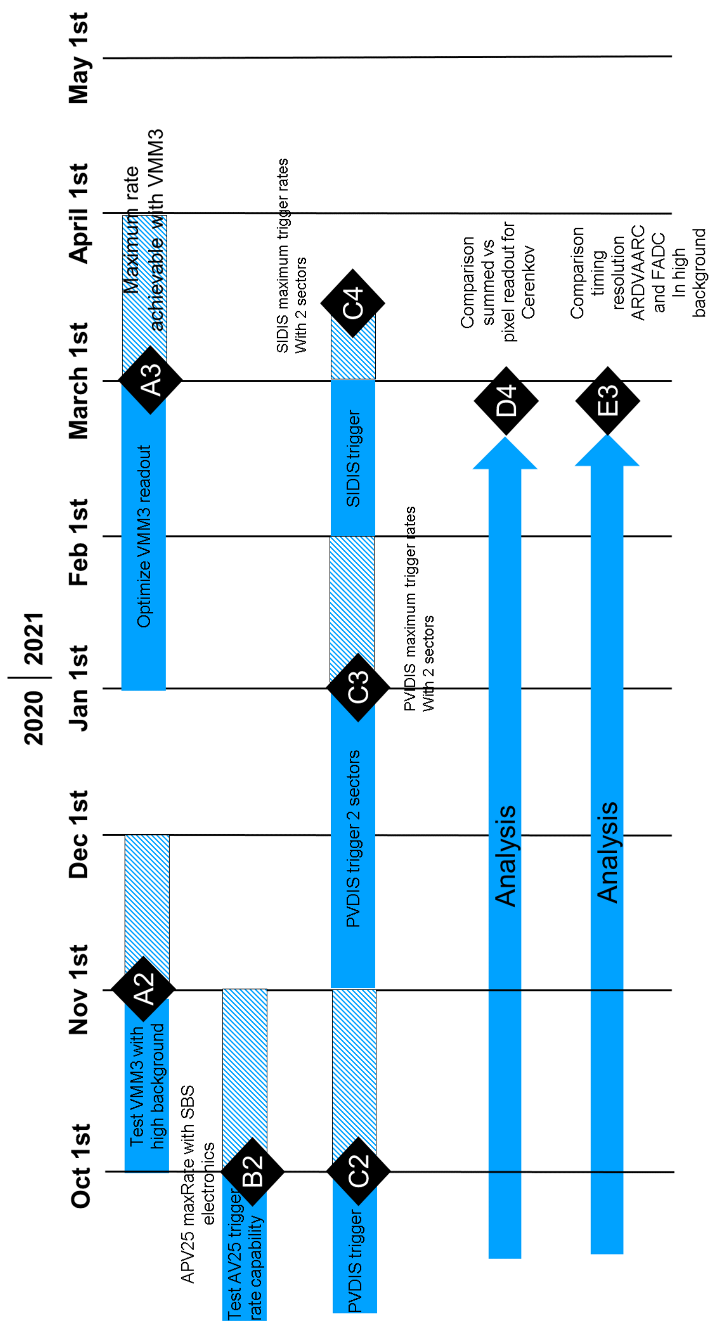

Figure 5: Timeline for data acquisition for the last 6 months of Pre-R&D activities. Solid boxes indicate major activities and striped boxes represent float.

Task	Man/week
Ecal trigger	4
GEM performance	4
FADC VXS/cluster readout	4
FADC tests	12
Data transfer silo	4
Deadtime for PVDIS	12
Data reduction algorithm	12
L3 farm need evaluation	8
Cherenkov readout	8
Test stand - beam test	8
PVDIS trigger prototype	4
SIDIS trigger prototype	8
High Resolution timing readout	4
SPD readout and test	4
VMM readout setup	12
Total Man/weeks	108
Total FTE	2.25

Table 4: Personnel required to carry out DAQ Pre-R&D. Funds are budgeted only for the postdocs, except for VMM readout setup which requires an electronics engineer. Jlab Physics staff will lead the Pre-R&D effort. Nine months of staff time will be contributed by JLab and are not included in this budget.

Item	mat.(K$)	per. (K$)	Contract (K$)	Total k$
DAQ	227.3	294.45	78.25	600

Table 5: Summary of budgeted materials and personnel, including overhead for DAQ.

- Milestone A2 November 1st 2020 : VMM3 will be tested with detector in high background using X-ray and radioactive sources to study behavior of the VMM3 and ensure signal can be well separated from background.
- Milestone A3 March 1st 2020 : after optimization of the readout, we will determine what is maximum rate achievable for the VMM3 GEM readout

APV25 In case we want to reuse electronics from SBS to reduce electronics costs, we need to ensure the existing electronics can reach at least 100 kHz

- Milestone B1 June 1st 2020 (+ 1 month contingency) : while the intrinsic specs of the chip should allow 200 kHz trigger rate using one sample, some development is needed to determine if this is achievable with the existing electronics from SBS. It involves enabling the APV25 buffering and optimizing the data transfer of the readout

- Milestone B2 : Determine rate limits of APV25 trigger rate and same testing in high occupancy environment October 1st 2020 (+1 month contingency)

2.6.2 DAQ test stand and rate tests

DAQ

- Milestone C1 April 1st 2020 : develop fast FADC readout (through VXS) to eliminate VME bus data bottle neck
- Milestone C2 October 1st 2020 : after the full trigger for PVDIS is completed, maximum trigger rate of the setup will be studied for one single sector
- Milestone C3 Feb 1st 2021 : communication between two sectors will be implemented , maximum trigger rate of the setup will then be studied this will be close to final PVDIS setup
- Milestone C4 March 15th 2021 : SIDIS will be implemented and maximum trigger rate will be determined

Cherenkov readout

- milestone D1 February 15th 2020 : Setup FADC crate for Cerenkov sum testing
- milestone D2 April 15th 2020 : record beam data using total sum and FADC
- milestone D3 : Test Cherenkov with MAROC in high background sample with beam.
- milestone D4 February 15th 2020 : complete analysis conclude if pixel readout is required.

Time of flight

- Milestone E1 February 1st 2020 : acquire and setup AARDVARC evaluation board
- Milestone E2 May 15th 2020 : acquire data of scintillator with beam
- Milestone E3 February 15th 2021 : complete analysis and determine achieved timing resolution with AARDVARC and compare to FADC resolution

3 High Rate Test of MaPMT Array and LAPPD Using a Telescopic Cherenkov Device

3.1 Overview

Future Cherenkov detectors at facilities like the SoLID at JLab will rely on arrays of MaPMTs in high rate environments. It is essential to test the response of MaPMT arrays under high-rate with modern electronic readout systems and gain-enhancing WLS coating to help guide decisions in design and provide input for realistic simulations. Specifically, these tests will allow us to evaluate and help mitigate risk associated with PID and trigger design in the SoLID detector at Jefferson Lab. To achieve this aim, a new telescopic Cherenkov device (TCD) will be constructed. The TCD will use an array of 16 MaPMTs inside a tank constructed from industrial PVC piping. The TCD is designed to record signals from simple analog-summing as well as digital read-out electronics. The TCD will collect data parasitically at Jefferson Lab under high-rate conditions. Comparative analyses of N_2 and C_4F_8 radiators, arrays with and without WLS coating, and read-out electronics will be performed. The results will be used to design efficient trigger logic and background-suppression algorithms, and help maximize efficiencies of future detectors.

3.2 Introduction

Today, many scattering experiments in nuclear and particle physics designed to address the most compelling science questions require high intensity probe beams in order to provide the necessary luminosity to either measure rare processes with high statistical precision or search for new phenomena. Examples of such beams are the high intensity electron beam impinging on fixed targets at Jefferson Lab or colliding a high intensity proton beam on an electron beam at an electron ion collider (EIC). Consequently, the next generation of particle detectors used in these experiments will need to perform efficiently in a high luminosity and large acceptance environment such as those in the SoLID program at Jefferson Lab, or future experiments at facilities like the EIC.

One such detector is the threshold Cherenkov counter, which traditionally is used to provide an online identification of relevant particles directly in the trigger. The latter allows a start of a read-out of all relevant information in the rest of the experiments' detectors. The traditional Cherenkov detector relies on photon detection given by a number of single anode large circular glass window (from 2" up to 5" diameter) photo-multipliers tubes (PMTs). Their performance is also significantly degraded by the presence of magnetic fields of the order of few Gauss. Furthermore, at high luminosities the large background environment amid the complexity of the trajectories of particles entering these detectors require the use of large photon detection arrays (example 20 x 20 cm^2) for photo-detection. Multi-anode PMTs (MaPMTs) hold the promise of solving these issues with an adequate research and development effort [10].

MaPMTs are different from traditional tube PMTs in a number of ways. Most obvious is the change from a cylindrical to cuboid shape. With this change comes the advantage of tiling the square windows MaPMTS into larger continuous detection arrays. In addition, any array will consist of independent MaPMTs units and each MaPMT is subdivided into many individual pixels giving great flexibility in devising a signal collection scheme with pixel information. For example, Fig. 6 shows the signal and background response of the SoLID Heavy Gas Cherenkov (HGC) and how it could potentially benefit from the additional pixel information for background suppression. The multi-pixel readout of MaPMTs requires unique front-end electronics, such as MAROC (multi-anode-read-out-chip) readout chips [7], connector boards, and FPGA interfaces. With MaPMTs we will take advantage of the independent units and granularity of each unit (in pixels) to mitigate the effects of high background environment. Finally, coating the MaPMTs windows with a wavelength shifting (WLS) substrate will increase their overall Cherenkov photon detection efficiency to a level that rivals the best quartz windows PMTs.

Given the foreseen impact on SoLID and other future experiments, the MaPMT's large array response and performance in a high-rate environment deserves further studies given the aforementioned properties. A telescopic Cherenkov device using MaPMTs with a large photo-detection array to address some of the challenges of high luminosity and high background environment will be invaluable for the successful design and operation of these counters in SoLID.

3.3 Summary of Test Objectives and Design Criteria

The primary objective of the TCD is to test the MaPMTs and electronics under similar running conditions as those expected in future experiments using SoLID at Jefferson Lab, or at facilities like the EIC. Specifically, this detector will test the Cherenkov signal response from an array of 16 MaPMTs under various high-rate configurations to help mitigate risk and guide design of the SoLID Cherenkov detectors.

- Bench Tests and Calibration

  The TCD will be assembled and tested with cosmic radiation at the Jefferson Lab test lab facility, or in a representative university laboratory space. The goal of the bench test will be to pre-test each component of the assembled device including: the gas-system operation, the data acquisition hardware and software, and the adjustable mount. Mirror alignment and calibration of the individual MaPMTs will also be performed in

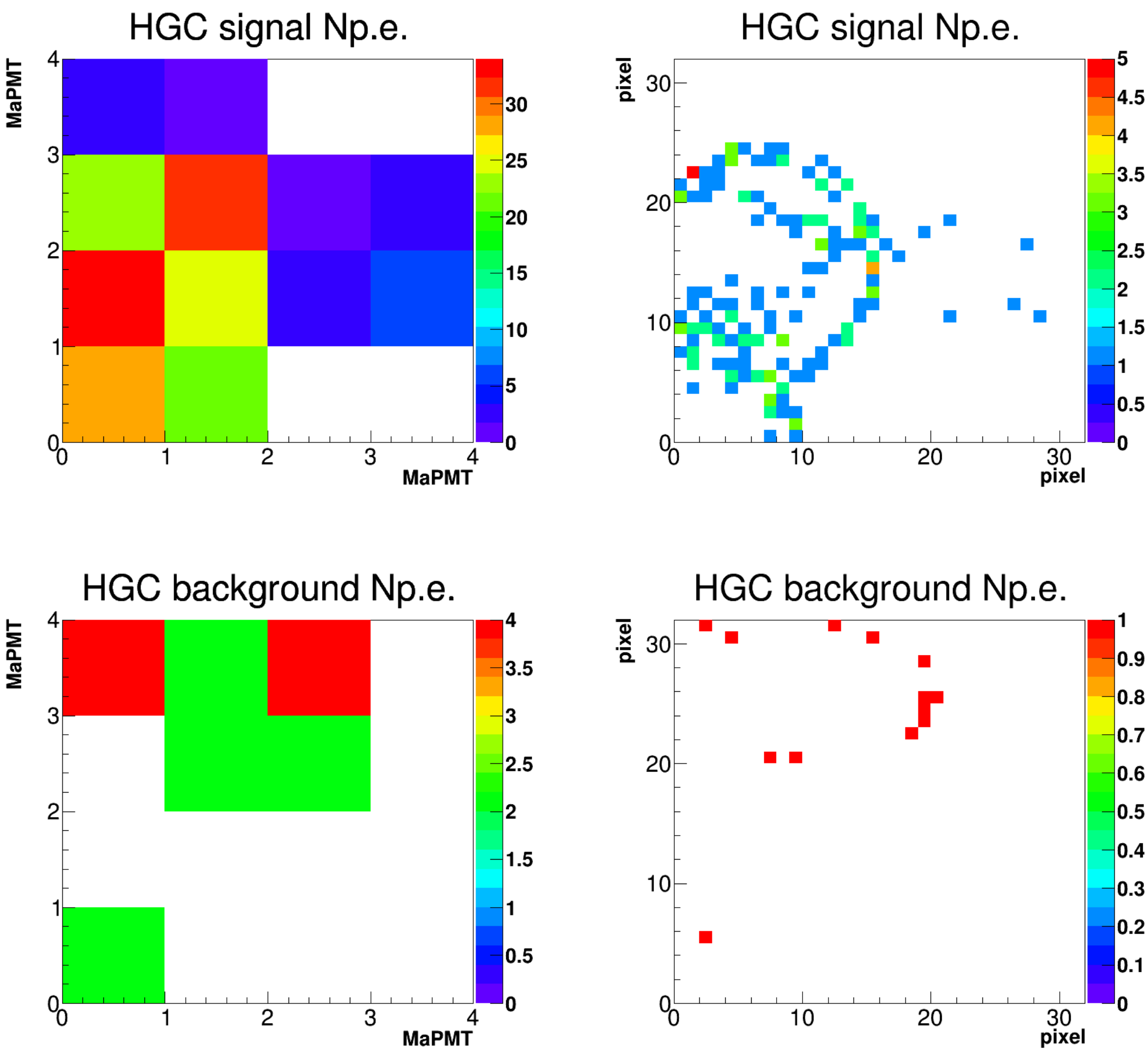

Figure 6: The simulated number of photoelectrons response of SoLID HGC is shown for one HGC sector with a 4x4 MaPMT (32x32 pixel) array. The top row shows the signal from one high energy pion directly from the target. The Cherenkov ring focused by a spherical mirror and collected by a light collection cone around the MaPMT array is visible. The bottom row shows the background from low energy secondary electrons and positrons. There are fewer number of photoelectrons and they are more randomly distributed. For both the signal and background, the same events are shown from the total sum (left) and pixel (right) readout. There is a lot more information that can be obtained by pixel readout and will be helpful to reject background if needed.

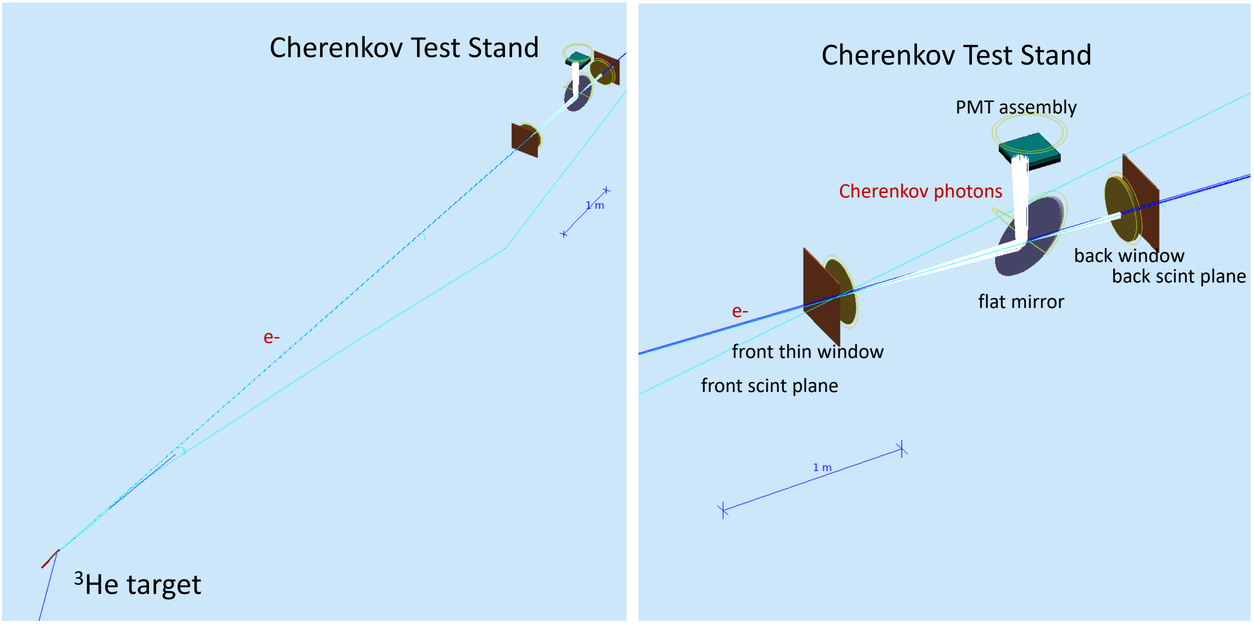

Figure 7: Simulation of the TCD in JLab Hall C. The left plot shows an electron (blue) from the polarized ^{3}He target entering the TCD at about 10m and 4 deg. Cherenkov lights (white) are produced by the electron, reflected on a mirror and collected by an MaPMT array. The right plot shows the same setup with zooming in on the device. The tank wall is invisible so that the internal components like the mirror and MaPMT array can be seen.

this step. Additionally, calibration of the scintillator planes and the electromagnetic calorimeter will be performed and their coincidence trigger will be tuned and integrated into the DAQ. Essentially, all critical steps needed for preparedness of data collection in the experimental hall will be done prior to installation where possible.

- Installation

  The TCD is designed to be placed in an experimental hall at JLab, where space is available, and pointed toward the beam-target vertex. Through coordination with scientists at Jefferson Lab, the TCD is expected to be installed in Hall-C in February 2020 during the scheduled experimental downtime. A possible setup in simulation is shown in Fig. 7. The actual rate of particles will depend on the running conditions of the experiment and the location of the TCD in the hall; in concert with the run plan for Hall-C experiment, we will initially place the TCD at large angle beyond the HMS spectrometer arm and then move the device at a small angle between the spectrometer the beam line to achieve a higher rate (between 1 and 4 MHz). Additionally, a small radiation hut will be needed to house the DAQ and computer electronics. Finally, some amount of remote access will be necessary to control the HV/power and to begin and end the data acquisition.

- Data Collection and Run Plan

  The run plan was designed to achieve all milestones listed in Sec. 3.7. An initial run will be performed with each MaPMT contributing one signal of summed pixels. This test will not include any of the MAROC electronics and each MaPMT signal will be collected in a FADC channel at the DAQ. Initially, we will collect data with N_2 gas at low and high rate to test MaPMT collection efficiencies and possible trigger combinations to maximize efficiencies for high rates above 1 MHz.

  The low rate configuration will place the TCD at 75 to 90 degrees with respect to the beam-line. The trigger rate can be further tuned by adjusting the calorimeter energy deposit required to fire the trigger. The high rate configuration will place the TCD between the HMS spectrometer and the beam-line at 4 to 6 degrees.

  After the initial run period, we will include the MAROC electronics and heavy gas testing. Again, high rate data will be collected for analysis of efficiency later, with similar conditions as those of the initial run. If time and resources permit, additional testing will be preformed without WLS coated MaPMTs and with alternative photodetectors.

  – Sum Electronics Testing

    Our default design is to have one FADC channel readout from one MaPMT. It requires summing of all of 64 pixels' analog signals into a total sum. The JLab detector group has designed and made a test summing board for this purpose. Besides the total sum output, the test sum board also includes 4 outputs of quad1 sum, quad2 sum, quad3 sum, and quad4 sum for testing. One limitation of the simple sum board is that each MaPMT has one common HV input for all pixels and cannot perform gain balancing among pixels. We will do bench tests with the test board first and then make enough boards for the TCD and carry out beam tests with both the light gas and heavy gas.

  – MAROC Electronics Testing

    Since each MaPMT has 64 pixels, and each pixel has one analog output, there is much more positional information available than a traditional PMT tube. However, trying to record the analog signal from each pixel into an ADC channel can put considerable strain on the DAQ. The MAROC electronics are used by CLAS12 RICH detector to read out each of 64 pixels of MaPMT H12700 to save the digitized information for later analysis [11, 12]. It also allows for gain balance among all pixels, which is not possible with the simple sum board. A total sum is always needed for SoLID light gas Cherenkov because it will be in trigger. Based on the CLAS12 RICH MAROC readout, the INFN Ferrara group designed a new MAROC readout with a total sum signal. The total sum signal is obtained by

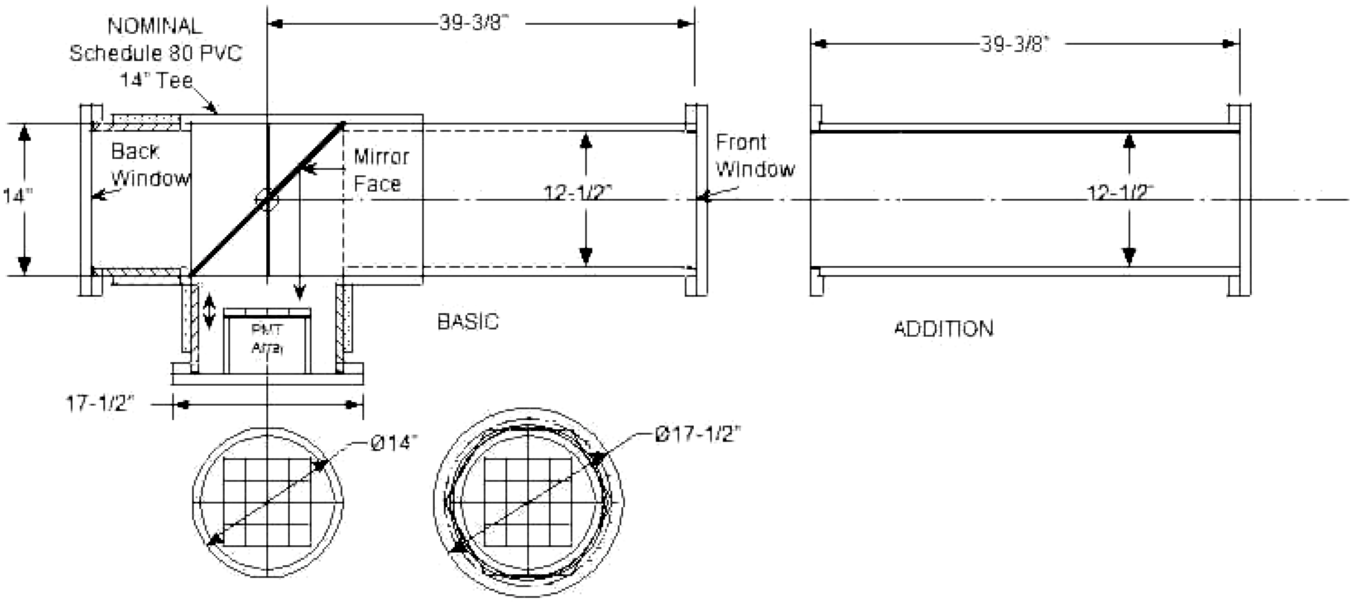

Figure 8: Tank design for the telescopic Cherenkov device.

modifying the MAROC ASIC board and adding an additional "SUM_OUTPUT" board. We plan to make a set of MAROC boards with the total sum for the TCD and do beam tests with both the light gas and heavy gas. We will compare test results between the MAROC with total sum boards and the simple sum board. First it can show how the total sum signals are different between the simple sum readout and the MAROC readout, where the pixel-by-pixel gain balance is possible. The findings can inform the trigger design. Secondly, we will learn how pixel information can help with offline background discrimination.

3.4 Design

The telescopic Cherenkov device is designed to achieve all milestones while minimizing design and construction cost. Its design concepts are outlined below.

- Tank

  The TCD's main tank is constructed from 2 main segments of polyvinyl-chloride (PVC) pipe (see Fig.8). The front end "nozzle" is a 40" long and 14" diameter pipe extendable to 60" or 80" with the addition of a second segment. The back segment is constructed from a 20" long T-connector pipe. The interior of the tank is padded with light absorbing paper to reduce reflections. The entrance and exit windows are 0.004 or 0.005 inch thick Aluminum, attached with flanges to allow pressurization up to 10-20 Torr above ambient and vacuum down to 10^{-6} Torr.

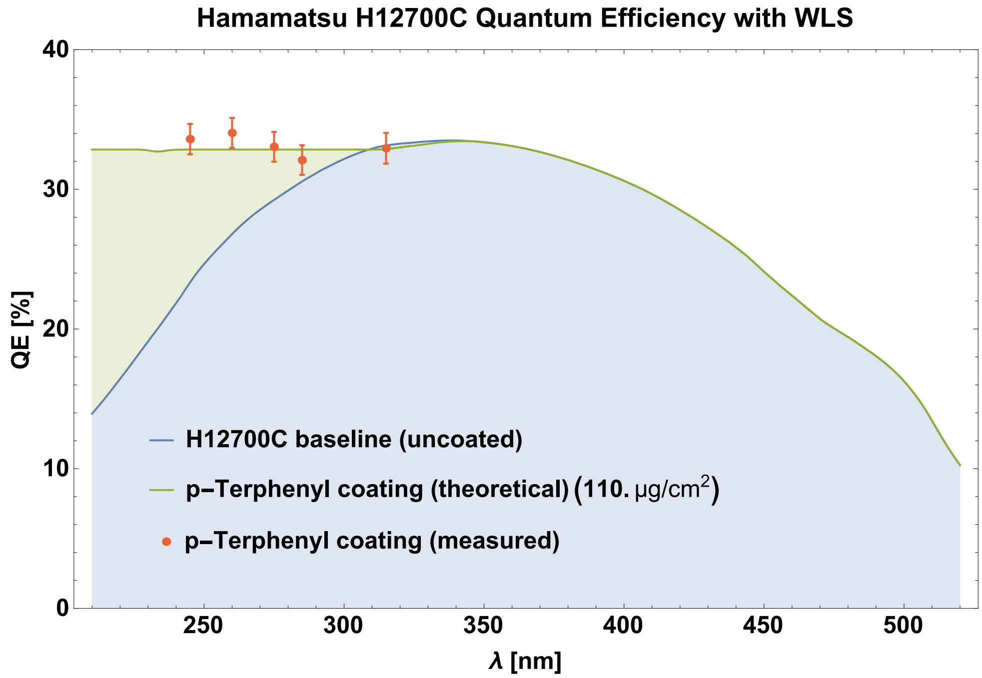

Figure 9: Nominal quantum efficiency as a function of wavelength for H12700C MaPMTs with (green) and without (blue) p-Terphenyl wavelength shifter. The red markers shows the quantum efficiency for a coated MaPMT as measured with monochromatic LEDs.

- Gas and Gas System

  The TCD is designed to use the light gas N_2 or heavy gas C_4F_8 at slightly over atmospheric pressure to avoid in-mixing of air. N_2 is selected as the light gas for its transparency to deep UV Cherenkov light, where the largest gain from p-Terphenenyl wavelength shifter PMT coating is expected [13], as shown in Fig. 9. The heavy gas C_4F_8 is selected for its good performance and wide availability. A simple gas-nozzle attachment allows the filling and evacuation of the tank while monitoring the attached pressure-gauge. The tank has two redundant safety relief valves that will automatically release the gas if the internal tank pressure exceeds 50 Torr over atmospheric pressure.

- MaPMTs Array

  Two arrays of 16 Hamamatsu 64-pixel multi-anode PMTs will be tiled 4-by-4, one will have its PMTs as received from the manufacturer (Hamamatsu), the other will have its PMTs UV glass faces coated with a p-terphenyl wavelength shifter to enhance the collection of UV light. Each array will be installed inside the tank at the top of the PVC T-connector. The MaPMT array will sit in a frame that can quickly attach and detach from the internal electronics, to allow easier switch between the WLS coated and uncoated MaPMT arrays. In the initial running period, the MaPMTs will connect to pixel-summation electronics which will use a back-plate with the appropriate feed-through adapters. For the second running period, the MaPMTs will each be connected to a MAROC electronics and a different MAROC feed-through backplate will be installed. A lead block shielding will sit outside the tank, between the target location and the PMT array (and MAROC electronics), to minimize accidental signal from direct electron interaction. The Duke University group has 16 Hamamatsu H12700 MaPMTs already purchased by the university funds and we are requesting funding for the additional 16 MaPMTs.

- LAPPD-GENII

  New technology devices that is superior to the use of MaPMTs but with competitive low-cost is under consideration for the photosensors of the SoLID Cherenkov detectors, these are large area picosecond photodetector (LAPPDs), a kind of low-cost MCP-PMT. LAPPDs with pads readout (25x25 mm2) are advanced enough in their development at Incom, Inc to be tested in real experiment condition. The LAPPD is resilient to high magnetic field (up to 1 Tesla) and offers a time resolution of the order of 50 ps, providing advantages in magnetic field shielding and background suppression using timing information. We will receive a 20x20 cm2 LAPPD-Gen II loaner from Incom, Inc with pixel size of 25x25 mm2. The anode readout configuration is 8x8 array, or 64-pixel, exactly the same as that of the tiled 16 Hamamatsu MaPMTs. The LAPPD will be coated with p-terphenyl WLS for Cherenkov UV photon detection as it employs a borosilicate glass. We will swap the MaPMTs with LAPPD, use the FADC250 as DAQ for a direct performance comparison with MaPMT array.

  ANL is also exploring an integrated readout of these devices that ultimately could make a trigger decision close to the detector for a high luminosity environment like that of SoLID. Relying on DOE-SBIR supported projects, we received a loaner of ASoC (a System-on-Chip) data acquisition system from Nalu Scientific, LLC. The ASoC has a 4 GHz sampling rate, 1 GHz band width and 35 ps timing resolution, can capture the full waveform of the LAPPD signals. We plan to test the ASoC evaluation boards integrated with FPGAs to explore its potential for SoLID online trigger decision. Meanwhile, a spare ASoC evaluation board will be placed in the appropriate region for radiation hardness test. The ASoC electronics will only be tested if time permits, and the test does not interfere with achieving all milestones listed below.

- Mirror

  A standard high reflection ($\sim$0.85 efficiency at 180 nm) flat mirror cut in elliptical shape to fit the cylinder at 45° is attached at the center of the T-connector, reflecting any Cherenkov radiation traveling along the length of the tank by 90 degrees and toward

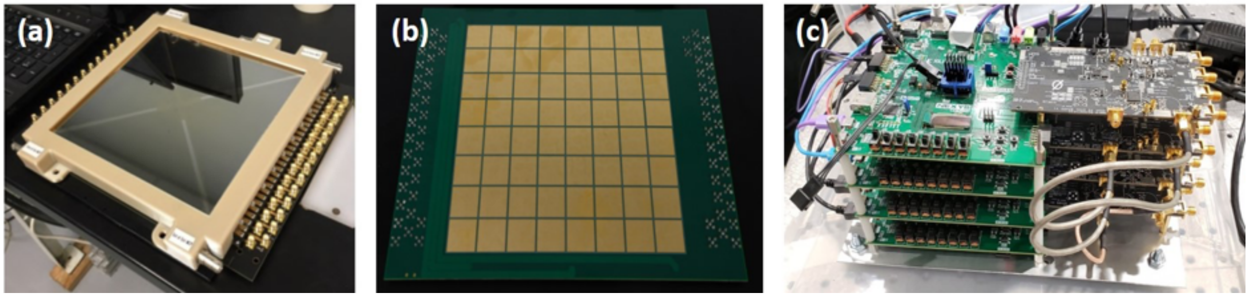

Figure 10: a) The 20x20 cm2 LAPPD device, and (b) 8x8 array, 25x25mm2, 64-pixel readout. (c) The Nalu ASoC data acquisition system, each evaluation board has 4 readout and attached to one FPGA, evaluation boards can be stack together for multi-pixel readout.

the PMT array. The mirror requirement is to have high reflectivity down to 180 nm, but a reflectivity measurement will be carried all the way down to a wavelength of 160 nm to take full advantage of the Cherenkov spectrum in combination with the use of N_2 and C_4F_8 as radiators and the wavelength shifter on the face of the MaPMTs. The mirror will be constructed with similar materials to the SoLID Cherenkov mirrors, a thin carbon-fiber or fiberglass frame covered with reflectively coated Lexan plastic film.

- Integrated Detectors

  At minimum, two scintillator paddles and an electron calorimeter in coincidence will be used to form the trigger. The coincidence trigger will require a signal from a scintillator paddle, and a signal from a calorimeter block. Additional scintillator paddles can help reduce accidental triggers, and can be integrated into the design if available.

- DAQ and Electronics

  A standard DAQ system with crate and computer will be housed behind shielding near the TCD set-up. The DAQ will use a single crate with NIM electronics to form the appropriate trigger. The signals from all scintillator and calorimeter PMTs will be sent to a FADC for data capture. The Cherenkov PMTs will be attached to either the pixel-summation board and then to a FADC or the MAROC board with the total sum and then to a FADC for the total sum readout and FPGAs for pixel readout, similar to the CLAS RICH electronics. DAQ components will be provided by JLab. Only the high voltage and low voltage power supplies are unique for the TCD test and included in the request.

3.5 Division of Responsibilities

The TCD construction and testing is a collaborative project between four institutions: Argonne National Laboratory, Duke University, Jefferson Lab, and Temple University. To help ensure a successful project, the responsibilities of those collaborating institutions are listed here. DAQ design and construction, along with installation of the device in an experimental hall and general Lab support is the primary responsibility of JLab. Construction, detector calibration, and data collection/analysis for the initial testing period, which includes N_2 gas without MAROC electronics, is the primary responsibility of Argonne National Laboratory and Temple University. Construction, calibration, and data collection/analysis for the second period of testing, which includes heavy gas and MAROC electronics, is the primary responsibility of Duke University. Project oversight will also be provided by Argonne National Laboratory. Beyond the designation of primary responsibilities listed above, it is expected that all four institutions will provide support to each other until we complete all the goals for the proposed device. The requested personnel in table. 3.8 is essential for completion of the project; however, existing personnel at Duke and Temple can cover all responsibilities, if necessary, but at some expense to their existing group research projects. Duke will try to hire a new postdoc to start in early 2020.

3.6 Summary of Construction, Calibration, and Data Collection Time-line

Bench tests of individual components, like MaPMT baselines and summing electronics will be completed by the time the full tank is constructed. By the end of 2019, the TCD will be fully assembled in the configuration to run with N_2 gas and logic-sum electronics. Calibrations and bench-tests of the assembled device will be completed in the following months. Installation of the TCD into the experimental hall is expected to occur in February 2020 during a scheduled experimental configuration change. Construction of the MAROC electronics interface between the MaPMT array and the DAQ will also be completed by March 2020. The following two and a half months will involve data collection and analysis, along with the completion of bench tests of the MAROC electronics and its integration into the final TCD configuration. After completing all data collection at the end of the Spring 2020 run, results will be analyzed and prepared for notes and publication by the year's end.

3.7 Milestones

The four following milestones are regarded as critical for the success of the TCD. Completion criteria for each milestone are summarized along with expected finish dates.

- Milestone 1: Construction and delivery of Cherenkov tank
  Complete: Early January 2020 + 3 weeks contingency
  Completion Criterion: The completed and assembled tank will be tested for light- and gas-tightness. The tank will be delivered to Jefferson Lab.

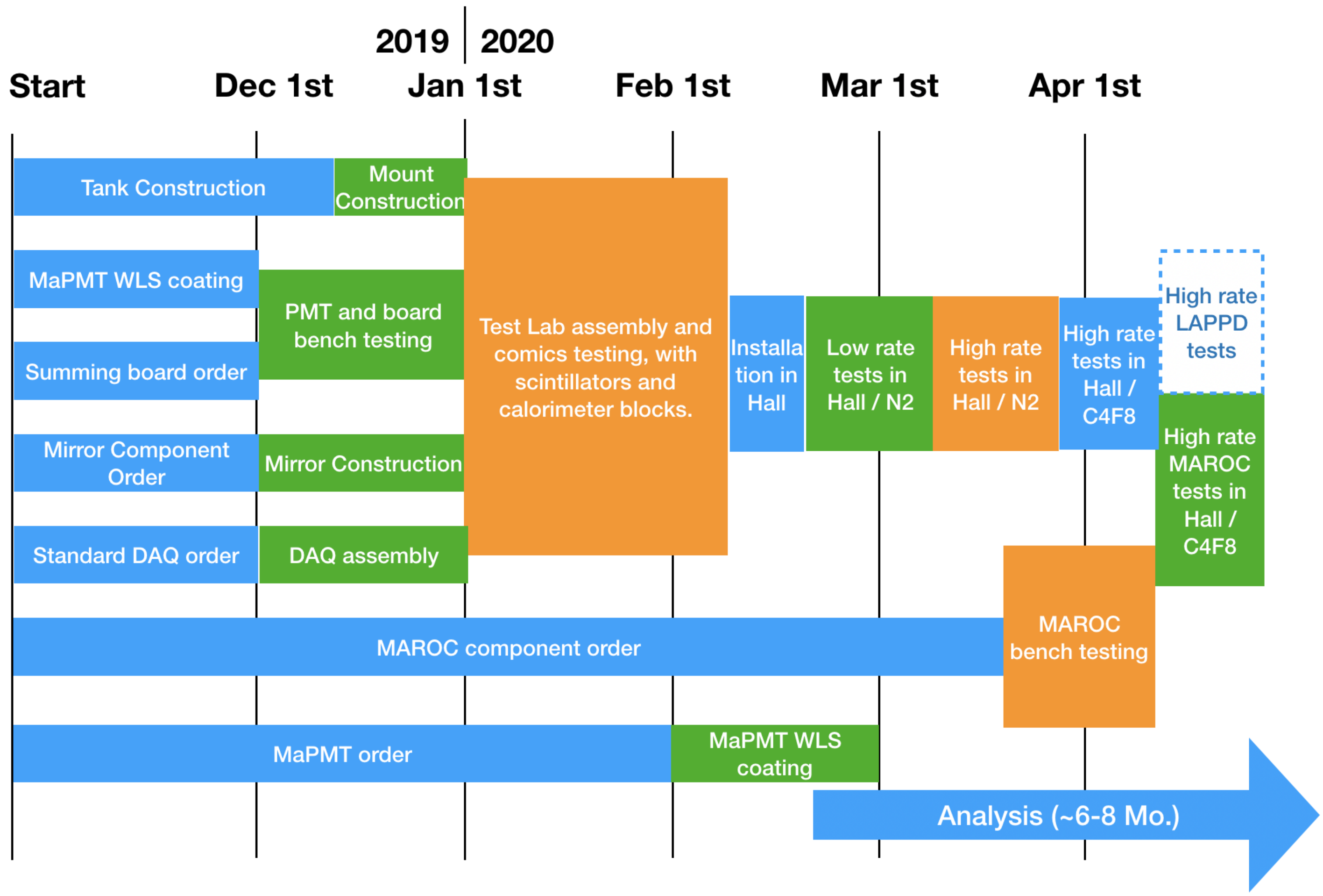

Figure 11: The complete timeline for construction and testing of the TCD. Solid boxes denote major tasks and objectives. Dashed boxes indicate tentative tests/objectives if time and resources allow. The color of the box is only present to help contrast between neighboring boxes and has no other meaning.

- Milestone 2: Cosmic testing and installation into experimental hall
  Complete: Mid February 2020 + 1 month contingency
  Completion Criterion: The tank will be completely assembled with secondary detectors (scintillators and calorimeter blocks). Electronics will be integrated into the DAQ and trigger and signal detection will be tested with cosmic rays. Completed detector will be installed into the experimental hall.

- Milestone 3: Collection and analysis of low and high rate data with electronic summing boards
  Complete: End of year 2020 + 2 month contingency
  Completion Criterion: Data will be collected with summing boards and N_2 gas and

C_4F_8 gas. The response of the MaPMTs will be characterized under high rate. The data will be analyzed for optimization of SoLID trigger, minimization of background, and realistic simulation parameters. The TCD will be placed at an angle less than 10 degrees for the high rate tests, and the rates are expected to match those highest rates for SoLID production, i.e. 1-4 MHz. For the low rate tests, the TCD will be placed at a wider angle where rates are simulated to be less than 1 MHz.

- Milestone 4: Collection and analysis of high rate data with MAROC electronics Complete: End of year 2020 + 4 month contingency
  Completion Criterion: MAROC electronics will be bench tested and installed into the detector. Data will be collected with C_4F_8 gas using the MAROC electronics. The data will be analyzed for minimization of background in SoLID, and more realistic simulation parameters. The TCD will be located at the same location for high rate as in milestone 3.

3.8 Budget Summary

The budget summary is tabled below. Table 6 lists the budgeted materials and personnel broken down with overhead and also breaks into the three institutions of Temple, Duke and ANL which will make the purchase. Table 7 is the summary of the budget.

Item	Component	Cost ($)	budget	budget	budget
Tank	PVC piping and connectors	7,560	Temple		
	PVC extension segments	890	Temple		
	Elliptical mirror	3,500	Temple		
	MaPMTs and mirror mounts	450	Temple		
	Vacuum flanges, valves, and plumbing	1,360	Temple		
	Window Material	200	Temple		
	Nuts, washers, etc...	250	Temple		
	Tank Subtotal	14,210			
Electronics	Hamamatsu H12700 MaPMTs	64,050	Temple		
	MaPMT signal sum board	2,000	Temple		
	Cabling and misc. for sum readout	1,000	Temple		
	Feed-through adapter for sum readout	1,000	Temple		
	MAROC with sum_output	41,700		Duke	
	Cabling and misc. for MAROC readout	5,000		Duke	
	Feed-through adapter for MAROC readout	1,000		Duke	
	HV and LV system	20,000		Duke	
	Components for LAPPD test	8,000			ANL
	Electronics Subtotal	143,750			
Add. Mat.	WLS coating	8,000	Temple		
	Lead blocks for PMT shielding	500	Temple		
	Vacuum pump, manometer and display	4,200	Temple		
	Test stand	4,000	Temple		
	N_2 gas	200	Temple		
	Mirror sample with reflectivity test	1,000	Temple		
	C_4F_8 gas	4,000		Duke	
	Additional Materials Subtotal	21,900			
	Requested Materials Subtotal	179,860			
	Overhead on materials	30,025			
Personnel	Post-Doc at Temple (0.8 FTE + Fringe)	52,520	Temple		
	Engineer at Temple (0.2 FTE + Fringe)	26,000	Temple		
	Travel for Temple	18,000	Temple		
	Post-Doc at Duke (0.8 FTE + Fringe)	51,000		Duke	
	Engineer at Duke (0.2 FTE + Fringe)	25,000		Duke	
	Travel for Duke	18,000		Duke	
	Requested Personnel Subtotal	190,520			
	Overhead on personnel	49,535			
	Requested Total	449,940			

Table 6: Total Cherenkov test budget collectively by the Temple, Duke, and ANL groups.

Item	mat. ($K)	per. ($K)	total ($K)
Temple	126.3	121.5	247.8
Duke	74.3	118.5	192.8
ANL	9.4	0	9.4
Sum	210	240	450

Table 7: Summary of the Cherenkov test budget for materials and personnel, including overhead.

4 Recommendations from JLab Director's reviews and pre-R&D plan

In the 2015 Director's review committee report, recommendation #11 called for "Develop an overall R&D plan for the project with a time line", our pre-R&D is a response to that recommendation. The recommendation #6 is 'The dead-times in the DAQ chain should be modeled". While the FADC dead-times have been modeled, the DAQ prototype in this pre-R&D plan will include the study of GEM and Cherenkovs dead-times. This recommendation will be closed following the completion of this pre-R&D plan.

In the 2019 Director's review committee report, recommendation #1 is "Make a pre-R&D plan, including a notional schedule, that resolves all significant technical questions if implemented. Include static/warm tests of the magnet." In our pre-R&D plan, we have identified the risks in the areas of DAQ and Cherenkov detectors for SoLID, and such risks will retire once we complete the pre-R&D plan.

Additionally, in the comments and suggestions section of the 2019 report, the committee wrote: "The project team should put a modest additional effort into re-evaluating alternative approaches. These could include trade-offs such as 1) . . . use of MCPPMTs on the LGC and HGC, ... 7) additional robustness (and physics?) using multi-anode readout of the MAPMTs on the Cherenkov detectors versus summed readout". The pre-R&D plan will also allow us to explore the aforementioned comments and suggestions made by the review committee.

5 Appendix: UVa X-ray Test facility and prototype GEM modules available for the readout system evaluation and characterization

The evaluation and characterization of VMM and APV-25 readouts developed as part of this pre R&D will be done using pulsar and simulated signals on the bench at Jlab, as well as by using a MOLLER type large GEM detector and the X-ray test facility in the Liyanage lab at UVa. The large GEM prototype, built as part of the EIC detector R&D at UVa is shown in Fig. 12.

The UVa X-ray test facility (shown in Fig 13) includes a flux x-ray tube, high power radioactive sources, as well as trigger scintillators of many different sizes and thicknesses. This setup is located within a large (1.5 m x 1.5 m x 2 m), heavy wooden walk in cabinet shielded with a 3 mm layer of painted lead sheet. A "scaffold" structure made of Aluminum extruded struts is attached to the inner wall of the cabinet to allow the mounting of GEM detectors of different sizes.

The test is performed within a 1.5 m x 1.5 m x 2 m hut made of wood. The outer surface of the box is covered with 3 mm lead sheet as radiation protective layer. An X-ray tube is placed 70 cm away from the GEM detector and uniformly covers the whole active area of the GEM detector. The X-ray acts as large size of random backgrounds and a ^{90}Sr radiation source is placed around 10 cm away from the GEM detector acting as the hit of interest to study the characteristics of the GEM detector. An overall picture of the setup is shown in Figure 13

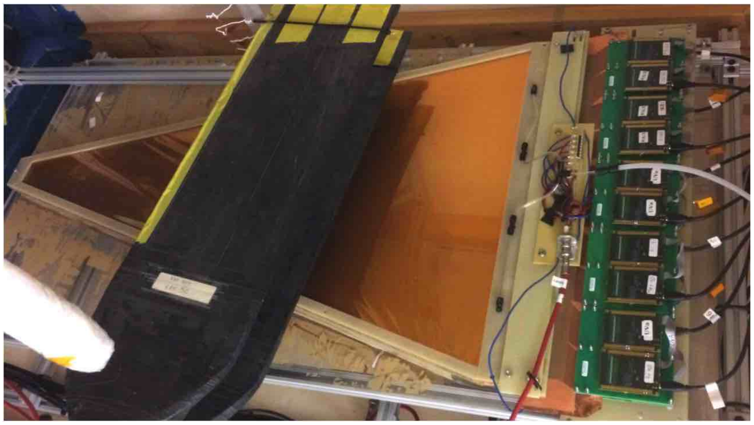

Figure 12: EIC GEM prototype-II built by the UVa group (pictured here installed and tested in the UVa X-ray test facility with APV-25 electronics). This GEM module will be used for the VMM and APV-25 readout evaluations proposed in the DAQ part of the pre R&D plan presented here. The main features of this prototype: geometry, size, the readout structure and the read-out strip layout (with all channels being readout from the other edge of the module), are all similar to what is proposed for MOLLER GEMs. As such, this prototype provides and excellent test-bed for the evaluation and benchmarking of the readout proposed here.

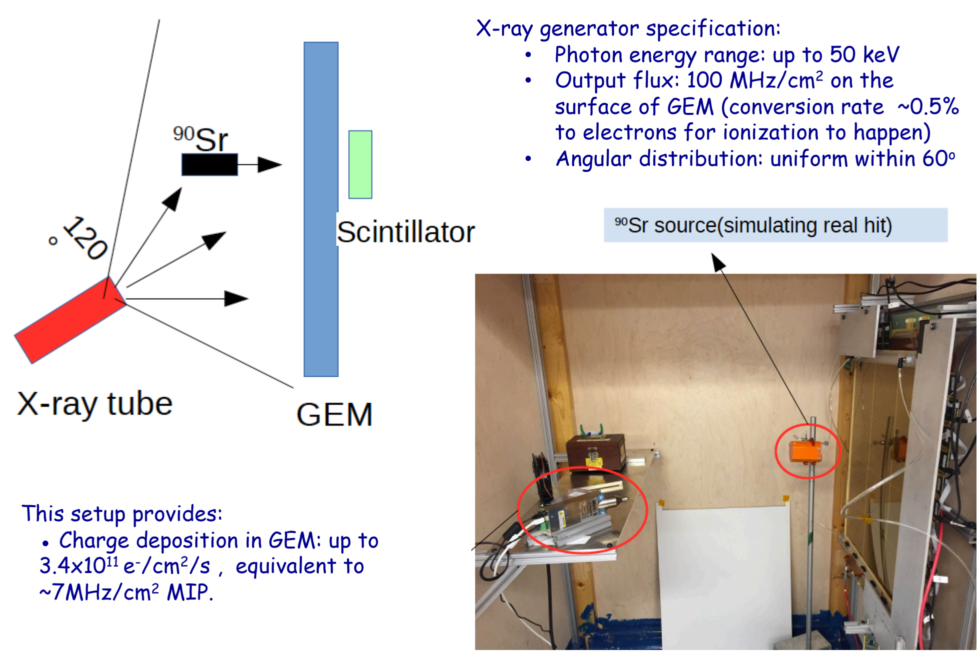

Figure 13: The UVa X-ray test setup

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