SoLID pre-R&D
Second Quarterly Progress Report

May 2020 to August 2020

SoLID Collaboration

September 22, 2020

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1 DAQ

1.1 Summary

This chapter summarizes the SoLID DAQ pre-R&D activities for the second quarter, from May 2020 to August, 2020.

The five main on-going tasks (A-E) for this pre-R&D are:

- A) GEM VMM3 readout high rate testing to determine trigger rate capability, behavior with pile-up and readout performance
- B) GEM APV25 readout high rate testing : show that 100 kHz trigger rate is achievable with existing readout hardware developed for SuperBigBite (SBS)
- C) FADC developments for fast readout and triggering
- D) Beam test of gas Cherenkov readout with analog sums and MAROC chip
- E) Time of flight using the NALU sampling chip

Milestone B1 due June 1st 2020 is complete.

Milestone C1 due for April 1st 2020, was delayed due to additionnal time spent to investigate APV25 issues for B1. Expected to be completed on January 31st 2021.

Milestone D3 is cancelled since beam will not be available. We are setting up a test bench and expect to have required data by end of January 2021.

Milestone E2 is being delayed while a spare is being manufactured. Completion is expected by December 15, 2020.

1.2 Milestones

1.2.1 GEM testing milestones

A) VMM3 We are studying the behavior of the VMM3 in high background and are determining the maximum trigger rate that can be achieved.

Milestone	Objectives	Expected Completion Date	Status
A1	Finish development of VMM3 direct readout	April 1, 2020	Complete
A2	High rate testing with detector	November 1, 2020	Started
A3	Optimized VMM3 setup for maximum data rate	March 1, 2021	Started

Figure 1: VMM3 evaluation board

A3 : A Prototype front-end board is being developped – The board will support 128 VMM3 channels and mount on a GEM detector with a high-pin count connector. It is designed with dual readout paths. The 10 GbE optical readout path allows for easy connection to a PC or network switch and is suitable for lab test stands or low radiation environments. The GBT optical readout link uses rad hard components designed for CERN LHC experiments and is expected to be used for SoLID data readout. The module has a hit rate capability of several MHz per channel at a 200 KHz trigger rate. The conceptual design was finalized and components have been chosen. A scheme for powering the module under radiation and non-radiation conditions was developed. The printed circuit board design (layout, signal routing) is approximately 50% complete. Firmware development for the 10 GbE readout mode has started and component acquisition is underway.

A2 : While waiting for delivery of VMM3 chips for the prototype board, we have procured a GPVMM evaluation board as shown in Fig. 1. The GPVMM evaluation board makes 12 direct readout outputs available on a connector. This connector is cabled to a Xilinx FPGA development board through a mezzanine card for readout of the direct outputs as shown in Fig. 3. No hardware design is required for this system. Readout of the FPGA board is via 1 GbE, so high-rate operation is possible. All hardware and adapters necessary to construct this system were acquired. Firmware development for the FPGA readout board is underway. Much of the firmware designed for this system can be used in the Prototype VMM front-end board. The board was operated successfully at home using the internal

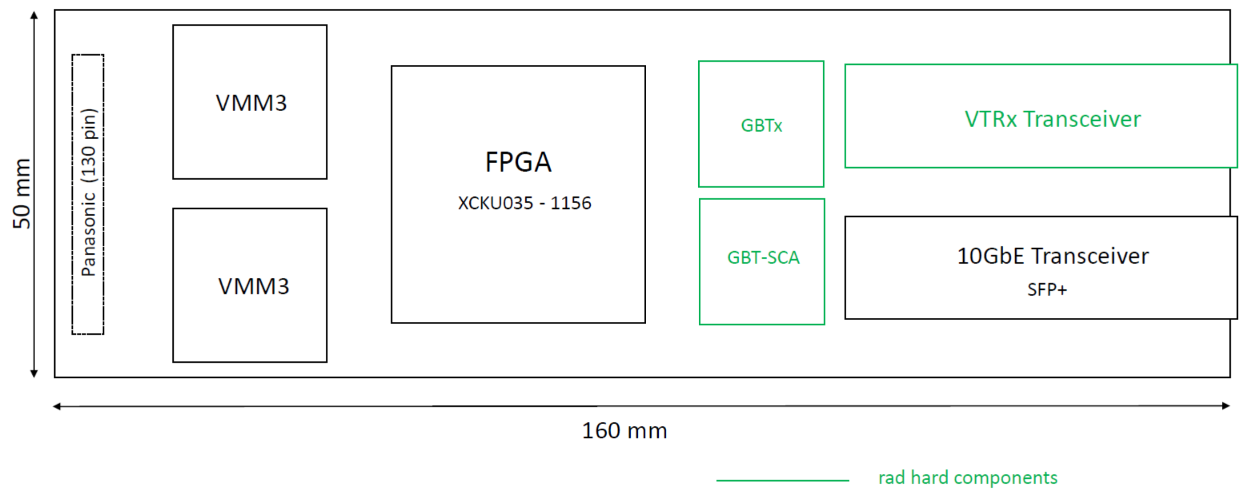

Figure 2: Prototype VMM front-end board

pulser with the VERSO software provided with the board.

The next step in VMM3 testing is to look at signals with an actual GEM detector. We plan to look at pedestal width for both standard and direct readout and signal to noise by looking at GEM cosmics signals for different integration times: 100 ns, 50 ns and 25 ns. This will give us a first idea about how the VMM3 behaves in high rate environment by using a pulser to generate high rates into the VMM3. Full testing with a GEM using an X-ray source will be performed when the prototype boards are complete as a large number of channels will speed up the data taking.

B) APV25 To test the feasibility of reusing electronics from SBS to reduce electronics costs, we will determine if the existing APV25 based electronics can reach a trigger rate of at least 100 kHz.

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

- Milestone B2, October 1, 2020 : Determine rate limits of the APV25 trigger and test in a high occupancy environment.

Milestone	Objectives	Expected Completion Date	Status
B1	Finish development of fast APV25 readout	June 1, 2020	Complete
B2	Determine maximum rate achievable with APV25	October 1, 2020	Started

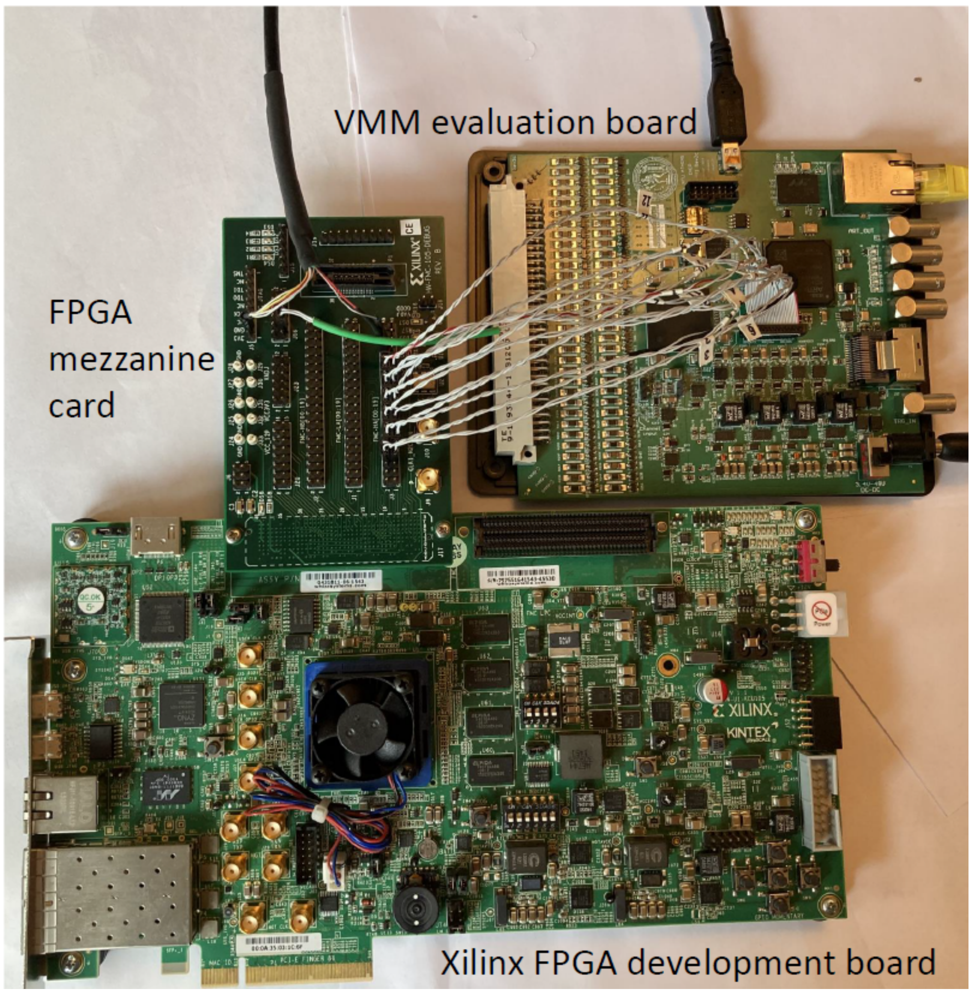

Figure 3: System for reading direct outputs from VMM evaluation board

B1 Complete. Noise issue on optical link power supply of MPD was discovered. Link speed had to be reduced from 2.5 Gbps to 1.25 Gbps. The optical readout firmware of the MPD & SSP is now reliable which will allow for fast APV25 readout. Depending on results of B2 we may need to revisit MPD firmware changes to achieve the highest APV25 trigger rate. The system being deployed with a large number of APV and MPDs as shown in Fig. 4.

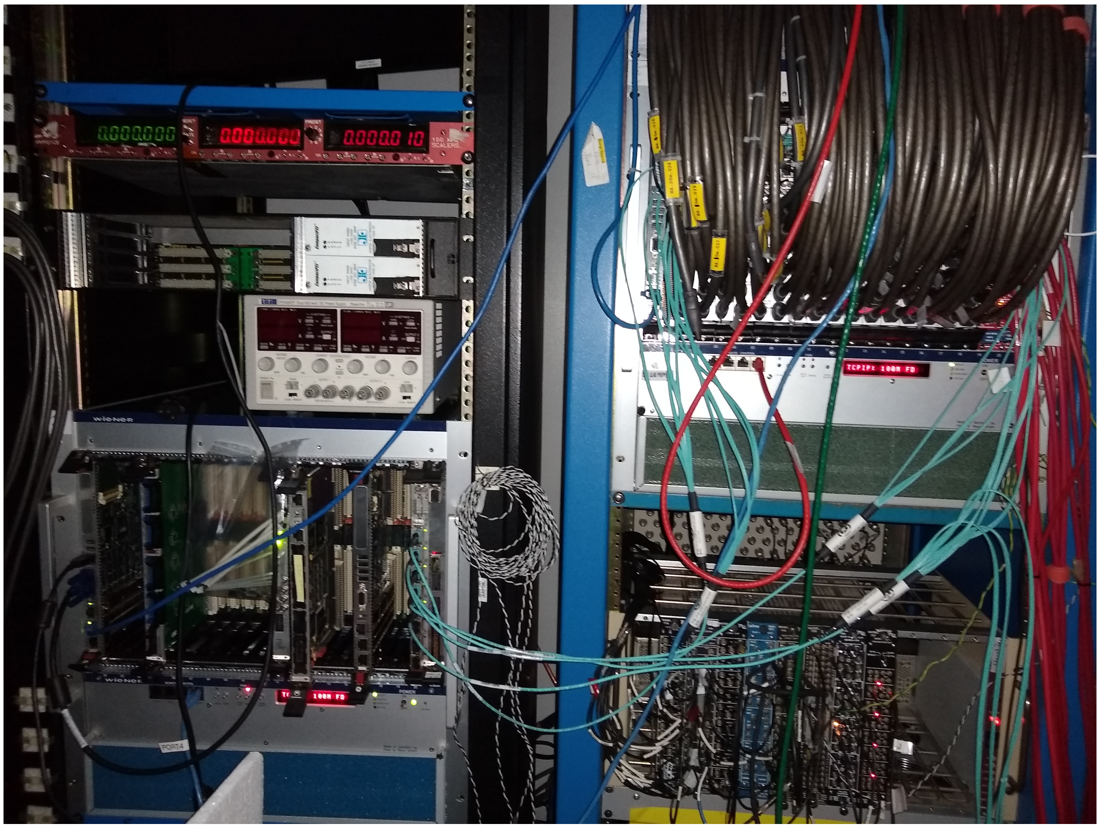

Figure 4: SSP optical readout (Left crate) connected to MPDs (Right crate)

B2: On-going. Initial testing with 6 samples per trigger has achieved ∼10 kHz trigger rate using 1 SSP with 1 MPD reading 5 APV chips. This is equivalent to 60 kHz readout rate at 100% occupancy in 1 sample mode (SIDIS occupancy was estimated to be less than 25%) . We are next planning to stress test this under various configurations (varying the number of APV25s per MPD up to about 25k channels) and expect to complete this testing by October 1st 2020.

1.2.2 DAQ test stand and rate tests

C) DAQ

Milestone	Objectives	Expected Completion Date	Status	Updated completion date
C1	Development FADC readout through VXS	April 1, 2020	On-going	January 31st 2021
C2	Testing PVDIS trigger functionalities and rate capability	October 1, 2020	On-going	March 1st 2021
C3	PVDIS trigger test with two sectors	February 1, 2021	Not started	May 1st 2021
C4	Test SIDIS trigger	March 15, 2021	Not Started	July 15th 2021

C1: On-going. VTP firmware plans have been developed and most firmware completed (see attached firmware block diagram Fig. 5 for VTP CODA hardware accelerator).

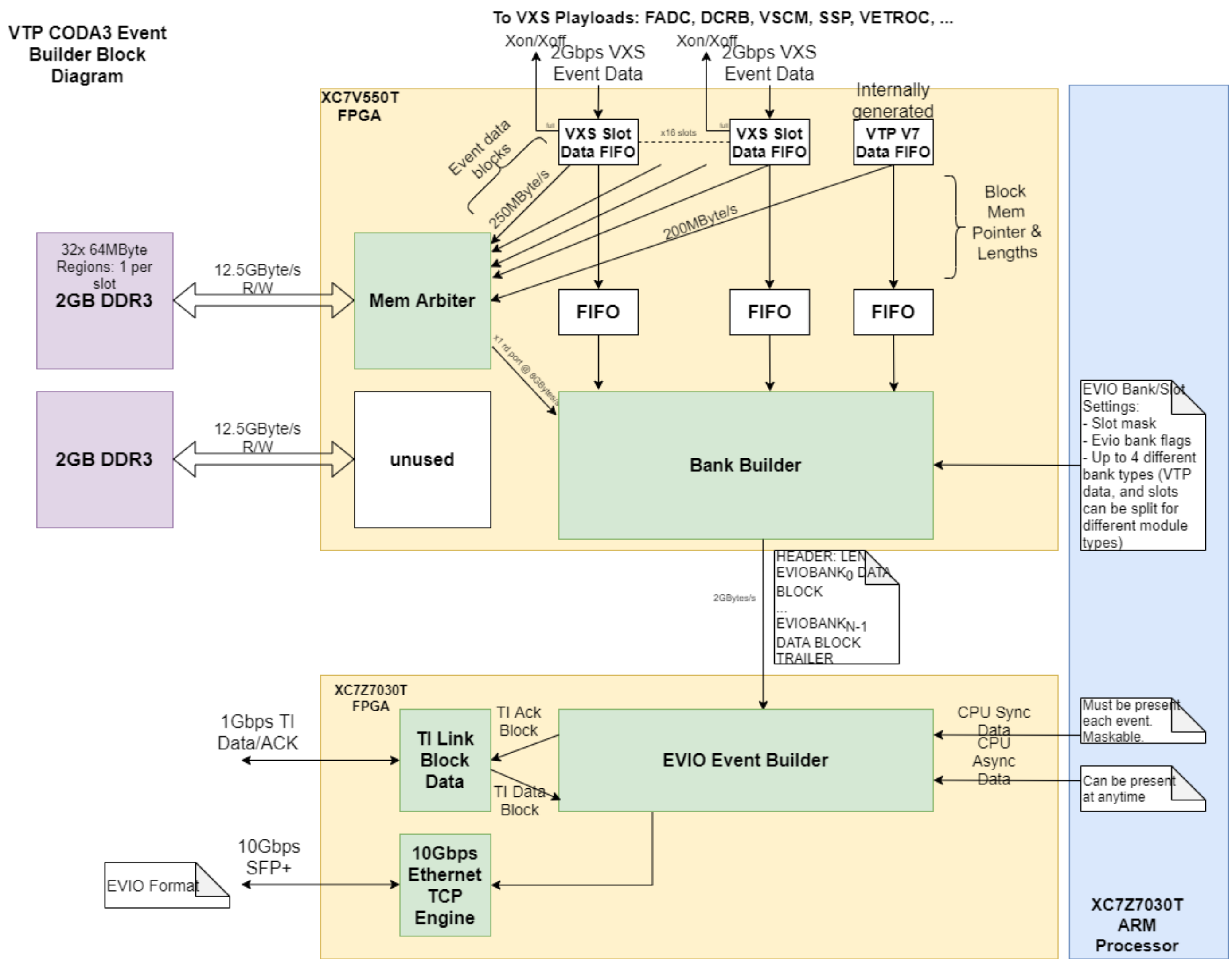

Figure 5: Block diagram of FADC VTP readout scheme

C2: On-going. The test stand for DAQ has started at UMass (Fig. 6). All components have been shipped, the CODA3 software and the readout program are being set up.

Figure 6: UMass DAQ test stand

C3/C4: Not started.

D) Cherenkov readout

Milestone	Objectives	Expected Completion Date	Status
D1	Setup FADC crate for Cherenkov sum testing	February 15, 2020	Complete
D2	Record beam data using sum and FADC	April 15, 2020	complete
D3	Record beam data using MAROC readout	Oct 15, 2020	Cancelled

Electronics was delivered from INFN and tested with LED and pulses. Beam test of MAROC electronics was cancelled due to lack of beam time availability. We will continue testing using radioactive source and cosmics on the bench. Some testing with an LED has been done and is summarized in the Cherenkov section 2.7.

E) Time of flight

Milestone	Objectives	Expected Completion Date	Status	Updated Date
E1	Acquire and setup AARDVARC evaluation board	February 1, 2020	Complete	
E2	Acquire data of scintillator with beam	May 15, 2020	Delayed	December 15th 2020
E3	Complete analysis and determine achieved timing resolution with AARDVARC and compare to FADC resolution	February 15, 2021	Delayed	May 15th 2021

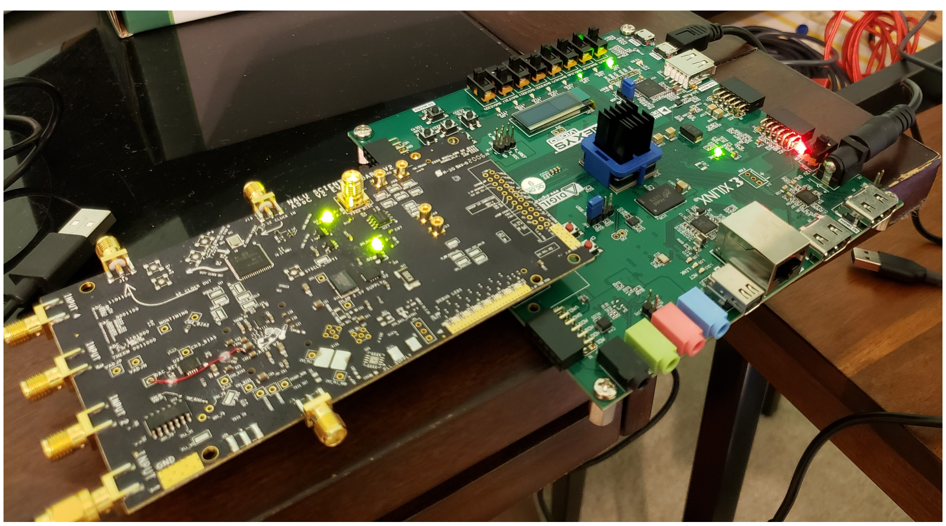

Figure 7: NALU ASOC evaluation board on a NEXSYS FPGA evaluation board

The NALU ASOC evaluation board was operated at home as shown on Fig. 7 but tests with a pulser are so far not successful. This is likely due to likely due to a hardware that is being investigated. A new batch of board is being fabricated and we will receive one. We plan to simulate high backgrounds by looking at cosmics signal along with a high activity radioactive source.

1.3 SoLID DAQ pre-R&D review

A SoLID preRD review was held on August 7th, 2020.

The committee was satisfied by the overall progress of the DAQ project. It had a few findings and recommendations.

Findings:

- The pre-R&D plan and presentation presents a plan to test inter-communication with 2 VTP cards. The SoLID experiment will eventually use 30 VTP cards. This presents a significant step up in scale. The committee feels that an intermediate step with 3 VTP cards, given the large anticipated rate, could be beneficial.
- The pre-R&D schedule has become a challenge in view of the ongoing pandemic. Its completion, in particular in the new realities of the ongoing pandemic, will require strong focus.
- Several of the collaborators involved in the pre-R&D identified potential opportunities to test fast network communication during future JLab experiment running, in particular during the upcoming SBS running period. The committee feels that the SoLID pre-R&D collaboration need one voice to approach the SBS collaboration and/or pursue other such opportunities.

Recommendations:

- In view of the uncertainties with the ongoing pandemic, including the possibility of renewed "shut-down", prioritize test-areas so that they can be operated remotely and that the data can be accessed remotely.
- Jefferson Lab is in the process of re-establishing beam for experiments in Hall-A and Hall-C. The window to take data is upperbound by scheduling of activities for future projects and is likely to close by mid-September for a (very) extended period. The pre-R&D collaboration should prioritize taking data early on this window.
- The pre-R&D collaboration should clearly delineate DAQ tests that can be done on the bench and those that (absolutely) need beam.
- Given that the VMM3 seems to be the preferred choice of readout chip, with the APV25 being a backup and hybrids being undesirable, it is important to understand as early as possible within the pre-R&D effort the maximum rate capability of the VMM3 chip. The committee recommends, if possible, advancing the determination of the maximum rate capability of the VMM3 chip.

Response to committee.

- Testing with 3 sectors was in the initial plan but was cut to two to fit the budget. Nevertheless, we will be able to test 3 crates for a short time by borrowing additionnal FADCs and VTP from the electronics group.
- Since JLab is still in MEDCON5, the test setup at the lab has been organized is such that it can be operated remotely. Only minimal access is needed for configuration changes such as cabling or installing new electronics. Most of the involved staff have been able to test hardware at home.
- While a beam test in conditions as close as possible to the experiment is desirable to validate expected rates from the simulation, effects of background can be simulated on the VMM3, Gas Cherenkov and TOF chips by looking at cosmics signals in the detectors while introducing backgrounds using pulsers and radioactive sources. This allows for the study the behavior of the detectors and the response of the electronics at high singles rates.
- In addition to the prototype development for the VMM3, two evaluation boards were acquired allowing testing of the VMM3 chip on a small subset of channels. The simulation shows results as expected for the 25 ns shaping time. This mode will be studied : effect of pile-up and signal to noise ration for the different shaping times will be tested in the next few weeks.

1.4 Budget / spending summary / procurement

Main new expenses were for the VMM3 prototype boards : 6.8 K$ for the VMM chips and for hardware for testing the evaluation boards. The VXS crates, VTP and CPUs were received.

Contracts for UVA and Gianluigi De Geronimo were postponed to fiscal year 2021.

1.5 Bench test planning

Since beam time is drawing to the end, testing of the different systems will be done by looking at cosmics signals simulating the physics signal and introducing background rates with pulser and/or radioactive sources to match the expected background rates from the simulation. We will also consider the FADC replay feature which allows for loading events from simulation in the FADC memory. This will allow testing of the full electronics chain with simulated data.

System	Cost ($)	Number	Total	Spent
VXS crate for DAQ modules	15,000	2	30,000	32,388
VTP - Module for triggering and data movement	10,000	2	20,000	17,050
SSP	6,500	1	6,500	0
TI - Trigger Interface	3,000	2	6,000	0
SD - Signal Distribution card	2,500	2	5,000	1,250
FADC trigger distribution card	2,000	2	4,000	4000
VME CPU	4,500	2	9,000	11,000
Trigger Supervisor	3,500	1	3,500	0
Hardware components for VMM readout test stand	25,000	1	25,000	6,775
APV25 GEM system	23,000	1	23,000	0
Cables/patch	400	160	64,000	8,000
Optical fibers	100	20	2,000	2,000
MAROC eval board	23,000	1	23,000	0
AARDVARC eval board	10,000	1	10,000	1000
Optical transceivers	50	32	1600	1600
Total M/S direct			210,600	85,063
Total request M/S			227,300	91,776
Workforce 2020	$130,000$	1.25	162,500	90,000
Workforce 2021	$133,900	1	133,900	0
Contract DG electronics	78,250	1	78,250	0

Table 1: Budget summary

	Budget ($)	Obligated ($)
Material	227,300	85,063
Personel	372,700	79,291
Total	600,000	164,354

Table 2: Budgeted and obligated funds summary (includes overhead)

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

2.1 Summary

During this reporting period, a project review from an independent panel was successfully conducted with favorable comments and constructive suggestions. The Telescopic Cherenkov Device (TCD) was installed at low angle, and high-rate data was collected using 16 WLS coated MaPMTs with our electronic simple-summing board. The TCD was returned to the low-rate configuration with a pixelized LAPPD as the photosensor, and data collection has started with CO_2 gas. We are optimistic that we will collect data for the LAPPD with C_4F_8 gas, and possibly collect data with MAROC electronics, if a parasitic opportunity would allows it.

2.2 Project Milestones

Milestone	Objectives	Expected Completion Date	Status
1	Construction and delivery of Cherenkov tank to Jefferson Lab.	Early January 2020	Complete (Q1)
2	Cosmic testing and installation into experimental hall.	Mid February 2020	Complete (Q1)
3	Collection and analysis of low and high rate data with electronic summing-board.	End of Year 2020 (+2 Month Contingency)	Collection complete (Q2), Analysis ongoing
4	Collection and analysis of high rate data with MAROC electronics.	End of Year 2020 (+4 Month Contingency)	Not Started

2.3 Budget / spending summary / procurement

To date funds have been used to purchase all the materials to construct the Cherenkov prototype tank with pressure controls, all connectors and cables for reading out signals of 64 channels from MaPMTs or LAPPD, mirror, 16 MaPMTs, wavelength shifter coating, radiator gas, MAROC readout boards and their cabling. Funds have been used for the mechanical engineering design and machining as well as electrical engineering support, travel

	Budget ($)	Q1 Expenses($)	Q2 Expenses ($)
Material	210.0	124,736	84,414
Personel	240.0	31,376	27,411
Total	450,000	156,112	111,825

Table 3: Budgeted and expenditures summary from both Temple and Duke for the Cherenkov prototype (includes overhead)

and transport of the prototype from Temple to Jefferson Lab, and the research personnel support for the approved activities at Duke and Temple.

2.4 Review of the Project

A review panel consisting of Ernst Sichtermann (LBNL, chair), Chris Cuevas (JLab), and Bob Wagner (ANL) met on August 7^{th}, 2020 with the TCD and DAQ teams to review the TCD pre-R&D proposal and progress. The committee was able to evaluate the progress and offer advice and suggestions given the truncated running time and delays at Jefferson Lab due to COVID-19. Information on this meeting's presentations are posted at https://www.jlab.org/indico/event/396/

The overall response from the committee was positive, and provided the following summary comments for the project:

- The committee finds that the pre-R&D plan is adequately formulated to address the technical risks for the DAQ system and the Cherenkov detectors.
- The committee is impressed with the progress that the pre-R&D team has already made in the current challenging environment, the quality of the presentations, and the quality of the data acquired to date.
- The committee encourages that the pre-R&D plan be seen through to completion.

For the TCD portion of the review, the committee stated in their close-out findings that:

- The committee is impressed that the pre-R&D collaboration has acquired data already with the Cherenkov test setup at large and small angles, and that the data-analysis as well simulations are proceeding well.
- The pre-R&D collaboration presented a prioritization of continued testing with the Cherenkov setup in Hall-C at large angles that had taking data with LAPPDs ranked

highest, followed by a test with heavy-gas (and LAPPD), and the MAROC as comparatively lower rank/priority. The committee feels that this prioritization is appropriate. The committee notes that CLAS12 and GlueX have provided experience with a MAROC DAQ solution and that SoLID appears to be an evolution of this solution. It might be possible to meet MAROC pre-R&D goals with bench tests rather than beam-tests in the very limited Hall-C window between now and the shutdown mid-September.

A single recommendation was presented by the committee:

- The committee recommends that the pre-R&D collaboration pursues the simulation(s) to satisfactory agreement with the acquired data as a means towards future design.

A full committee report has yet to be provided to the collaboration as of this quarterly report. However, discussions with the review committee and considering its recommendations have helped inform and guide the TCD collaboration with prioritizing remaining goals, considering the limited opportunistic running availability at Jefferson Lab.

2.5 High Rate Installation and Data Collection

The High Rate Installation of the TCD started on June 10 2020. The TCD was moved from the SHMS side (low-rate location) to a location between the beam line and the HMS at an angle of about 3.5 deg and 39 feet away from the target. A picture of the TDC at the high rate location is shown in Figure 8. The MaPMTs gain calibrations were checked and the calorimeter blocks were once more gain matched with cosmic rays. High-rate data, at least up to 4 MHz, were collected between Aug. 2nd and 6th with a calorimeter trigger. The online preliminary analysis shows promising results, indicating that MaPMTs are a viable option of the Cherenkovs' photosensors in SoLID's high-rate environment.

Figure 8: TCD at the high rate location, downstream of the target along the beamline, in Hall C.

2.6 Low Rate LAPPD Installation

After completing data taking in the high rate configuration, the TCD was moved back to the SHMS side in the low rate configuration (minimal interference with the running Hall C experiment) and the photon detector box was changed to the LAPPD box. Optimization of the LAPPD HVs was performed using an oscilloscope initially. The data taking with the CO_2 gas was completed on Sep 9, 2020. The Cherenkov tank was flushed of the CO_2 and filled with C_4F_8 during a hall access in the week of Sep 14-18, 2020. The LAPPD data analysis is ongoing. Pictures of the TCD at the low rate location and of the LAPPD box (open) are shown in Figures 9 and 10.

Figure 9: TCD at the low rate location is Hall C (LAPPD box in).

Figure 10: The LAPPD box.

2.7 MaPMT with MAROC sum readout preparation

We assembled the MaPMT with MAROC sum electronics into its readout box, shown in Figure 11. We conducted an initial bench test, and the original pixel readout and newly designed sum readout performed as expected. The readout is ready to be put in Hall C to take data if there is an opportunity. We are also planning more bench tests if the beam test will not happen due to the remaining limited beam time this year.

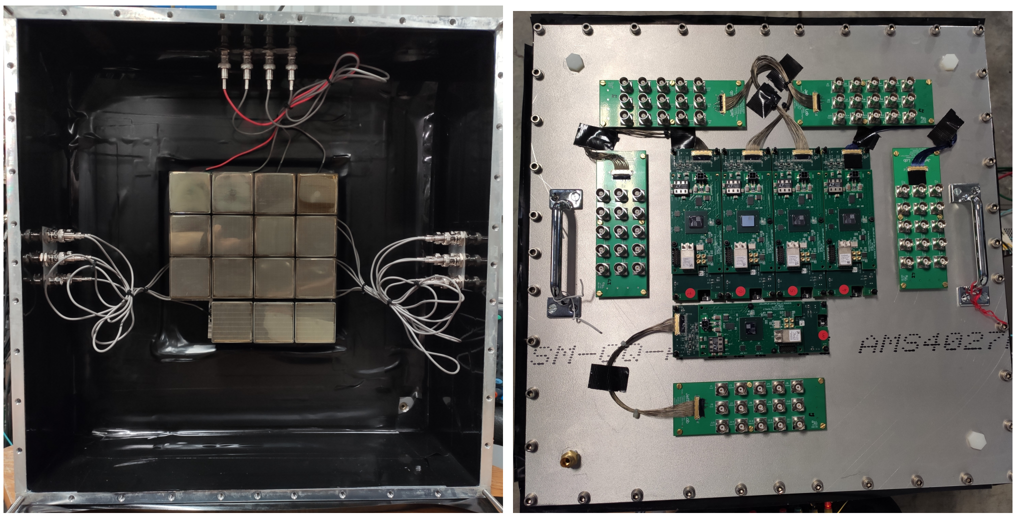

Figure 11: MaPMT with MAROC sum readout mounted in its readout box. The left photo shows the front view with 15 MaPMTs assembled. The right photo shows the back view with 5 sets of MAROC sum boards in the middle and 5 connector boards for the quads and total sum signals on the outside.

2.8 Analysis and Simulation

The analysis and simulation are focused on the setup with MaPMT simple sum readout for both the low rate and high rate condition.

2.8.1 Low Rate Analysis Progress

A toolkit for analyzing the raw waveform data taken from the FADC250 modules has been developed, and we have analyzed the low rate data with it. The data were taken with a total signal rate at about 320 kHz/PMT. The single photo-electron (SPE) peaks were extracted from the random coincidence events, as shown in Figure 12. The SPE amplitudes were then utilized to normalize the signal amplitudes for the corresponding channels. Figure 13 shows the total signal sum of all 16 MaPMT channels, grouped by the number of fired PMTs. Three prominent peaks can be identified from the signal sums: the random coincidence SPE peak (N_PMT = 1,2,3), the regular signal peak for the full acceptance of Cherenkov photons from a single electron (N_PMT = 4), and the signal peak for a pair-production event (N_PMT = 8). From this preliminary analysis, the number of photo-electrons for regular signals is found to be about 17.

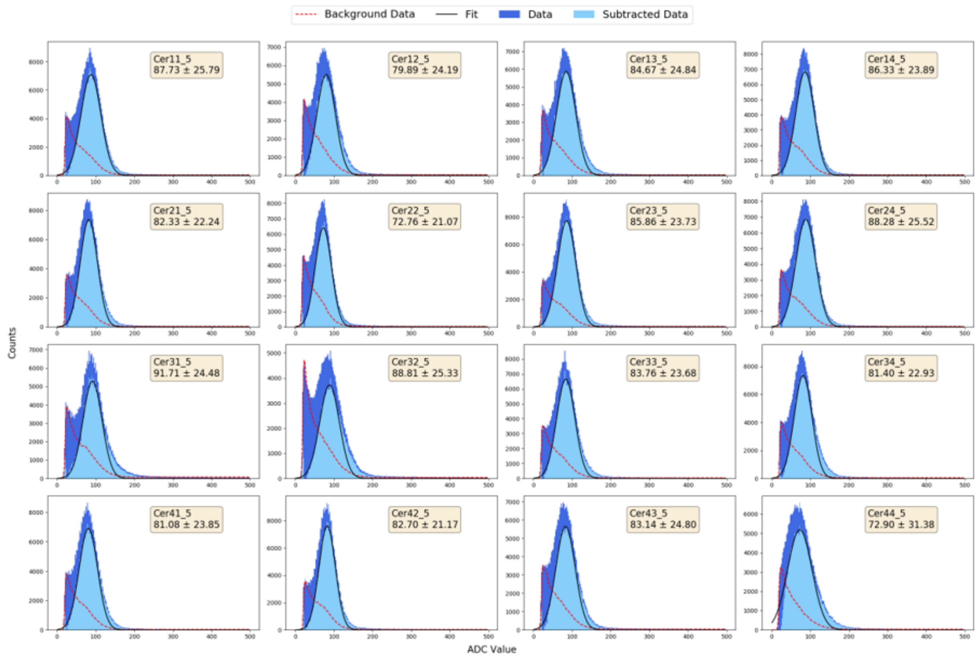

Figure 12: Single photo-electron signals from the MaPMT sum channels for low rate test. Here the dark blue shade represents the raw data with a random coincidence cut, the red dotted line shows the estimated dark current distribution, and the light blue shade represents the single photo-electron signals.

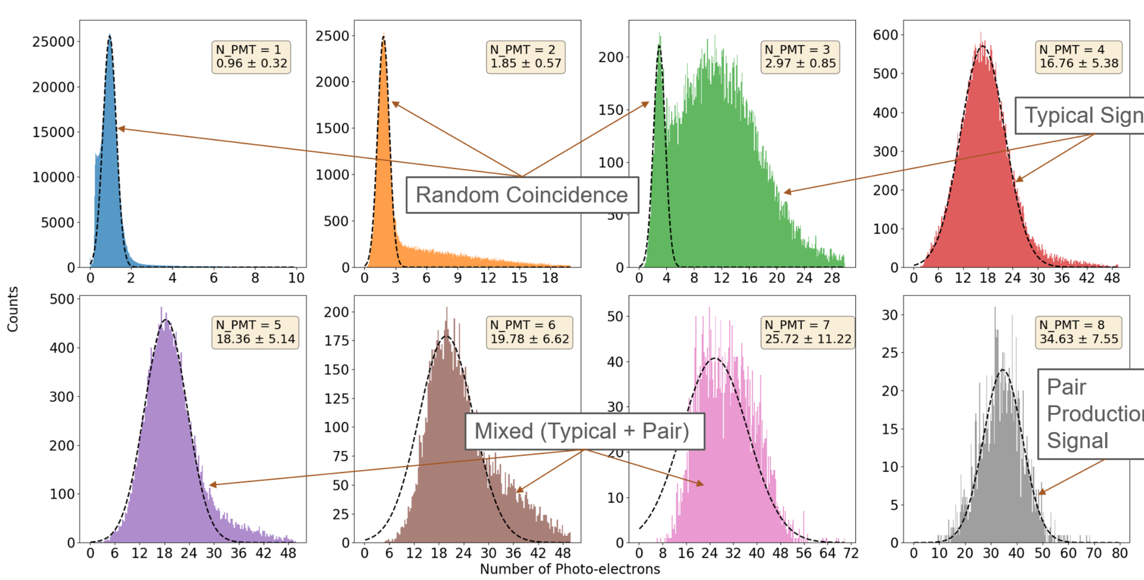

Figure 13: The signal sum of all the MaPMT channels, grouped by the number of fired channels, for low rate test. With the increase of the number of fired channels, the dominant signal shifts from the random coincidence to the Cherenkov process for a single electron and a pair of electron and positron.

2.8.2 High Rate Analysis Progress

We have also carried out a preliminary analysis for the high rate test. Figure 14 shows the signal sum results for the data taken with 1 μA beam at a rate about 4.8 MHz/PMT, which is over one order of magnitude higher than the low rate test. We have obtained a result that is consistent with the low rate test, showing the NPE for regular signals is about 17. The smaller contribution from the random coincidence signals is due to a higher trigger threshold set for the data-taken in the high rate environment. The result demonstrates that the prototype detector with MaPMTs works well with a total signal rate at the level of 4.8 MHz/PMT. More studies about the quadrant signals and possible clustering of them are ongoing.

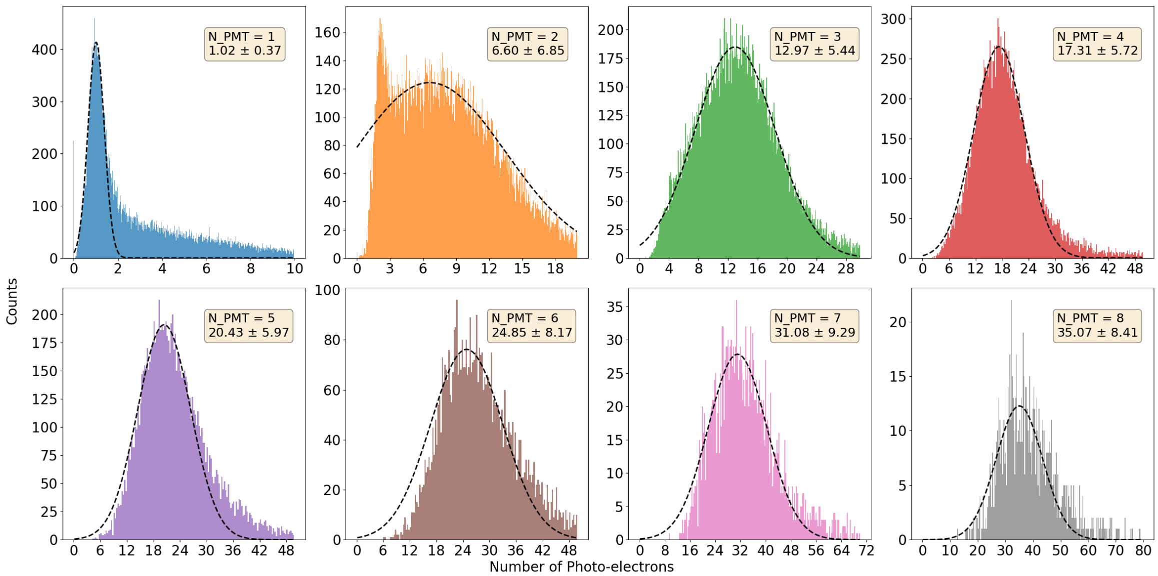

Figure 14: The signal sum of all the MaPMT channels, grouped by the number of fired channels, for high rate test. It shows a similar structure as in Figure 13.

2.8.3 Low Rate Simulation Progress

A Geant4 simulation of TCD, including the Cherenkov, EM calorimeter (EC), and the scintillator (SC) detectors was developed similarly to the SoLID simulation. The setup is shown in Figure 15. The measured WLS coated MaPMT quantum efficiencies are used and the Cherenkov optical physics cut-off is chosen to be 200 nm. We studied the resulting number of photo-electrons in the Cherenkov detector from two main sources, namely high energy scattered electrons and π^0 production with subsequent decay photons conversion into electron-positron pairs from the polarized ^3He gas target.

The preliminary result in the low rate data taking condition is shown in Figure 16. The π^0 decay particles give much larger signals than the high energy scattered electrons because the TCD is at 75° relative to the target.

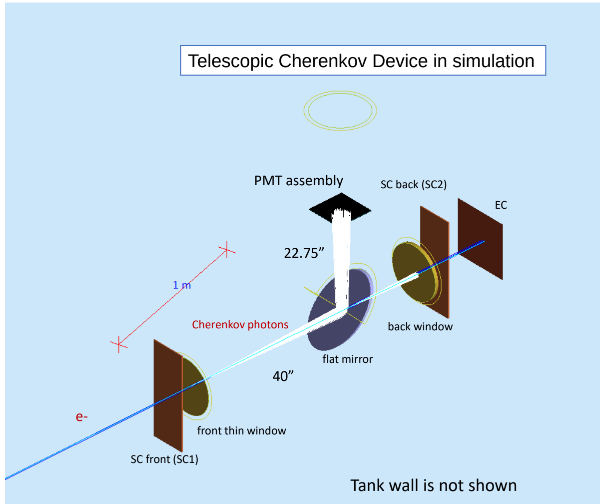

Figure 15: The TCD setup in the Geant4 simulation.

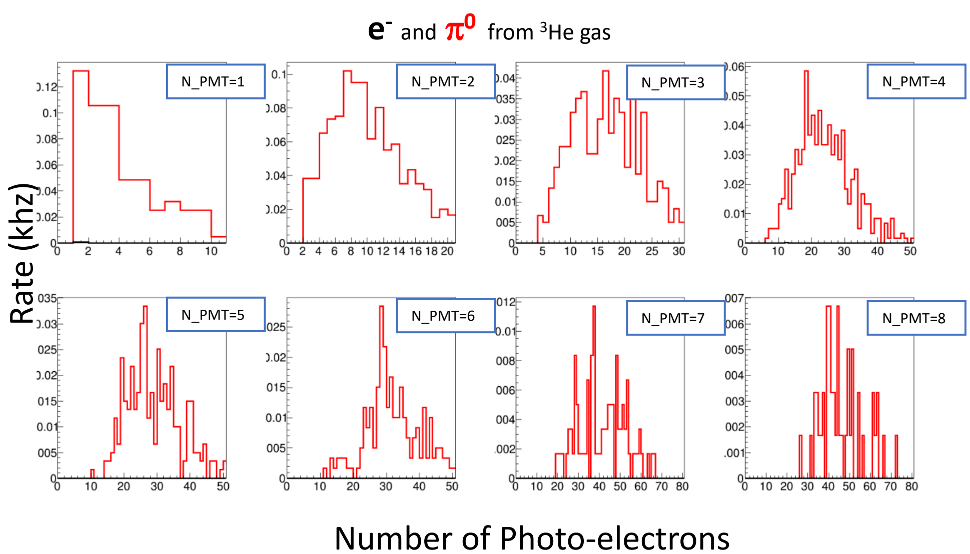

Figure 16: The preliminary simulation result of the number of photo-electrons at the low rate data taking condition. The result is presented in the same way as the low rate data in Figure 13.

2.8.4 High Rate Simulation Progress

The preliminary result at the high rate data taking condition is shown in Figure 17. The π^0 decay particles and high energy electrons contribute at the similar level because the TCD is at 3.5 deg relative to the target.

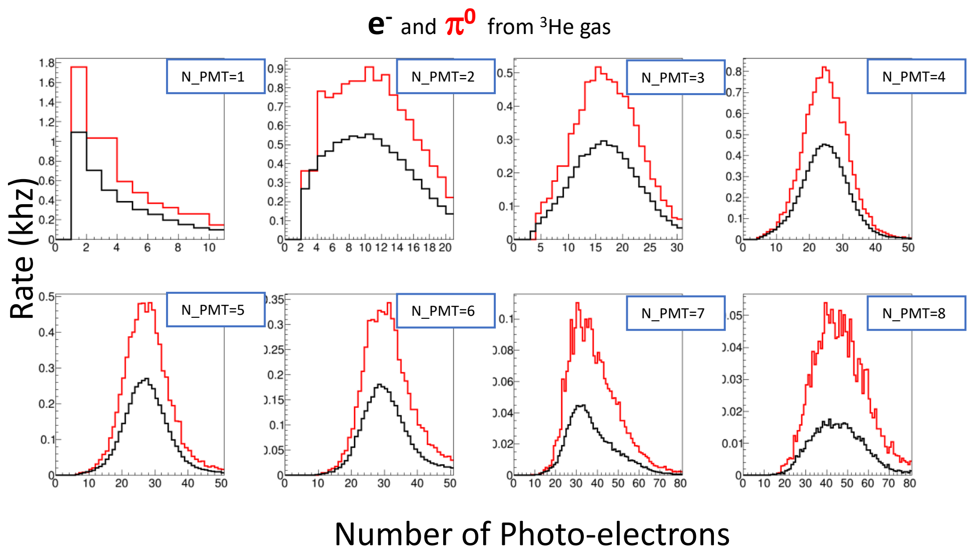

Figure 17: The preliminary simulation result of the number of photo-electrons at the high rate data taking condition. The result is presented in the same way as the high rate data in Figure 14.

The simulation results resemble both the low rate and high rate data. More detailed studies are ongoing.

2.9 Prioritization and Remaining Parasitic Opportunity

Jefferson Lab is scheduled to go into beam shutdown before the end of September. As of now, the TCD collaboration has collected data at low and high rate with the simple-summing electronics and an array of MaPMTs. Following the advice on prioritization from the review committee, data is now also being collected at large angle and low rate with the LAPPD electronics and CO2 gas. Following this test, we are optimistic that we will be able to test the LAPPD large angle configuration with C4F8 heavy gas. If time and opportunity permits, we will test the MAROC electronics with an array of MaPMTs following the heavy gas test. We are confident that the highest priority goals of this pre-R&D will be met with the data that has already been collected. After beam shutdown and all parasitic opportunity has been exhausted, remaining goals will be addressed to our best abilities on the bench.