SoLID pre-R&D
Quarterly Progress Report

SoLID Collaboration

May 8, 2020

Contents

1 DAQ

1.1 Summary

This chapter summarizes the SoLID DAQ pre-R&D activities for the first quarter. The pre-R&D activities started at the beginning of 2020, while the full budget was approved on February 20, 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 Cerenkov readout with analog sums and MAROC chip
- E) Time of flight using the Hawaii NALU sampling chip

There were four milestones by the end of the first quarter. Three (A1, D1 and E1) have been completed. For the fourth (C1), the work is on-going, while another milestone C2, which is scheduled to be completed by October 1, 2020, has been completed. Details are described in the next two sections. A digital trigger was developed and tested briefly with beam. GEM and FADC readout developments are making good progress with remote work albeit slowed down by lab closing. For the second quarter we expect a delay in the schedule due to the suspension of laboratory operations because of the COVID-19 pandemic.

1.2 Milestones

1.2.1 GEM testing milestones

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

Milestone	Objectives	Expected Completion Date	Status
A1	Finish development of VMM3 direct readout	A1 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

The VMM3 evaluation boards were ordered February and delivered April 5, 2020. We expect a few more weeks of testing to learn how to use the board. Ed Jastremzki (JLab fast electronics group) has powered the board and taken data with the provided software. Actual testing with a detector will be slowed down by the lab closure, so milestone A2 will be delayed.

B) APV25 To test the feasibility of reusing electronics from SBS to reduce electronics costs, we will determine if the existing 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 200 kHz trigger rate using one sample, some development is needed to determine if this is achievable with the existing electronics from SBS. 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	Started
B2	Determine maximum rate achievable with APV25	October 1, 2020	Not started

A scheme to readout the APV25 using the INFN board MPD through the optical link has been designed and is being tested for up to 24 MPD modules using the SSP module, developed for Jefferson Lab pipelined electronics, at data rates up to 200 MB/s. The development of a faster readout using the VTP module has started, it consists primarily of designing an adapter board to route signals from the MPD module (which reads out the APV25 chips) to the VTP processor module. This allows parallel readout of the boards. Data from the VTP is transferred to a host computer on a 10 GigE link (1.25 GB/s). The milestones B1 and B2 are expected to have some delay due to the lab closure.

1.2.2 DAQ test stand and rate tests

C) DAQ

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

Milestone C1 was delayed to support Cerenkov test run. The fast FADC readout through VXS has started beginning of April and is expected to be first tested by the end of June depending when lab operation is resumed.

D) Cherenkov readout

Milestone	Objectives	Expected Completion Date	Status
D1	Setup FADC crate for Cerenkov sum testing	February 15, 2020	Complete
D2	Record beam data using sum and FADC	April 15, 2020	On-going
D3	Record beam data using MAROC readout	May 15, 2020	Started

Milestone D1 was achieved at beginning of March with the digital trigger implementation. Cosmic ray data and a few hours of beam data were collected before the suspension of operations at the lab. More details are in the Cerenkov section. The MAROC boards were built by our INFN colleagues and the board were shipped to Jefferson Lab. These will be tested when work resumes at the lab.

E) Time of flight

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

AARDVARC evaluation board is available but can only accommodate a short timing window of 12 ns at the moment which will not be suitable for the time-of-flight scintillators used for the test, so we decided to loan an ASOC board for the test. FPGA boards were ordered to drive the ASOC board. The board and software were operated successfully meeting milestone E1 but testing with detector could not be done because of the laboratory shutdown. E2 will most likely not be achieved due to the lab closure and will be replaced by testing with a high rate radioactive source, which will be carried out once laboratory resumes operations.

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

2.1 Summary

The Telescopic Cherenkov Device (TCD) was built and delivered to Jefferson Lab. All electronics readout were designed and produced. Cosmic-radiation tests, calibration, and initial data collection were performed in the experimental Hall-C. Progress was made toward completion of the project, with two of the four proposed milestones reached. Preliminary analysis of the data collected is very promising. Mandatory COVID-19 closing of Jefferson Lab may affect the proposed timelines for completion of the remaining milestones. We expect to continue with data collection when the lab reopens and resumes operation with beam delivery to the hall.

2.2 Project Milestones

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

2.3 Construction and Delivery of Cherenkov tank to Jefferson Lab

The Cherenkov tank, components frame, and pressure system were assembled at Temple University and then delivered to Jefferson Lab on March 13$^{\text{th}}$, 2020. A summary of assembly and components delivered are listed below:

- The primary Cherenkov tank was assembled from 14" diameter PVC-pipe, and machine cut to the required dimensions. Inside the tank felt flocking was attached to minimize secondary reflections. Additional apertures were added to allow valves and gas flow, sensors, and an LED test light source. Large circular gaskets were added to secure the removable electronics housing boxes.

- Aluminum windows and PVC window frames were machined and pressure tested.

- Flat elliptical mirrors were constructed from carbon-fiber bases and Lexan reflective film. The primary mirror was mounted inside the tank and aligned to reflect light incident down the central ray of the tank onto the center of the photon detector array. The mirror assembly is shown in Fig. 3.

- All sixteen MaPMTs were coated at Temple University with the wavelength-shifting chemical p-Terphenyl.

- Two PVC electronics housing boxes were assembled, one for MaPMT with simple sum readout and one for LAPPD. Each housing box required 80 to 96 bulkhead BNC or SHV hermetic feed-through adaptors. Each housing box was designed to maintain structural and hermetic integrity while allowing detachable access plates in order to access the enclosed electronics.

- An electronics summing board was designed by the Jefferson Lab Detector Group and tested by the Duke University group. The board allows simultaneous readout of 16 MaPMTs, with separate signal from each quadrant of each MaPMT and the summed signal from the four quadrants. Additional cabling and low voltage power assemblies were provided by Temple and Duke Universities. An image of the 16 MaPMTs connected to the summing board can be seen in Fig. 6.

- A detector cradle was designed and assembled from 80/20 and machine cut aluminum to hold the tank and provide mounting points for the calorimeter blocks, scintillator planes, lead block shielding, and patch-panel and cable housing. The tank and cradle assembly is shown in Fig. 1.

- A pressure regulation system was assembled from a gauge pressure manometer, two solenoid valves, a desktop PID controller with laptop interface, and the required cabling.

The assembled tank was tested for pressure tightness at Temple University before delivery to Jefferson Lab. All items were then transported to the experimental staging building (ESB) at Jefferson lab where DAQ assembly and cosmics testing was then completed (see below). The dimensions and specifications of the tank are shown in Fig. 2.

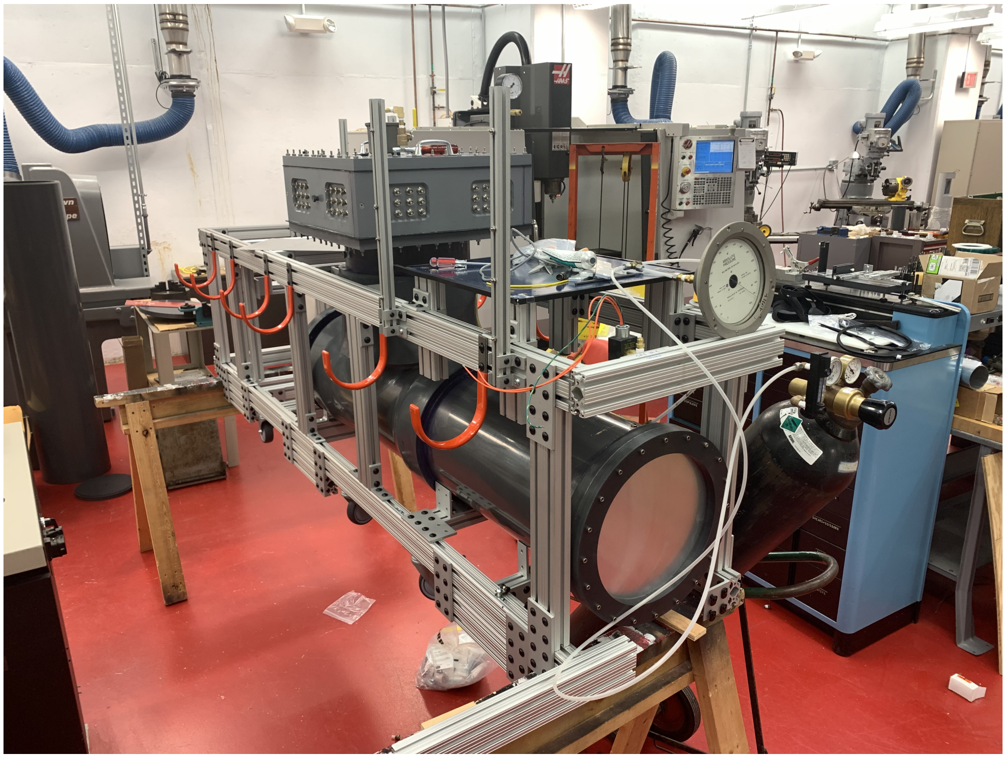

Figure 1: The PVC tank and 80/20 cradle assembled at Temple University before delivery to Jefferson Lab.

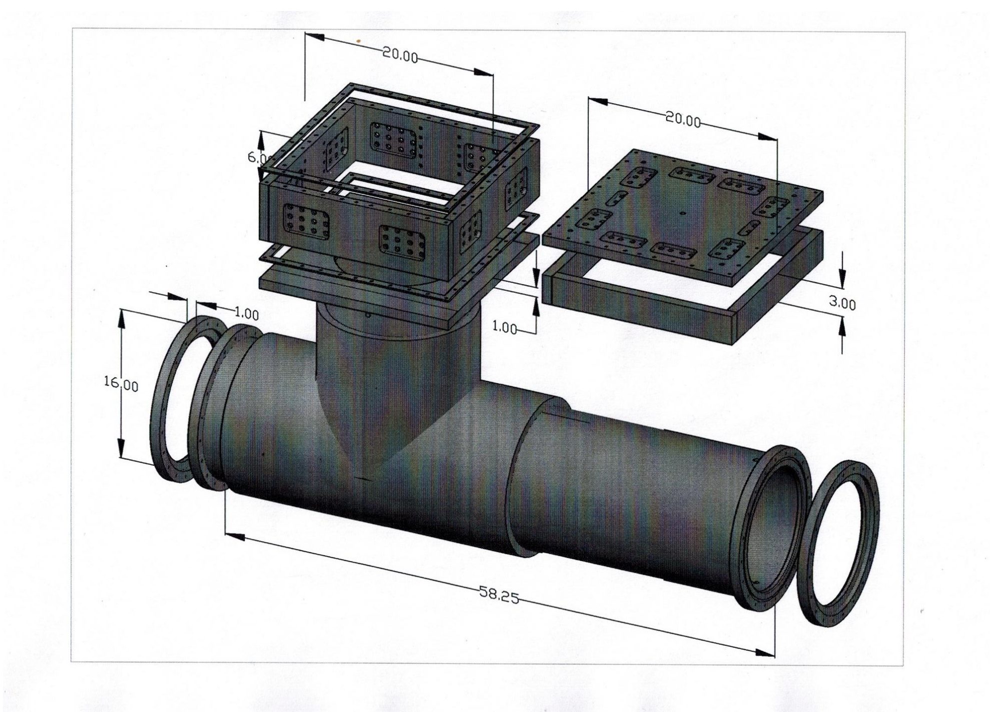

Figure 2: The Cherenkov tank design, as delivered to Jefferson Lab. The schematic shows both the electronics housing box for the MaPMT summing board and the housing for the LAPPD electronics.

Figure 3: The Lexan and carbon fiber assembled mirror, before installation into the Cherenkov tank.

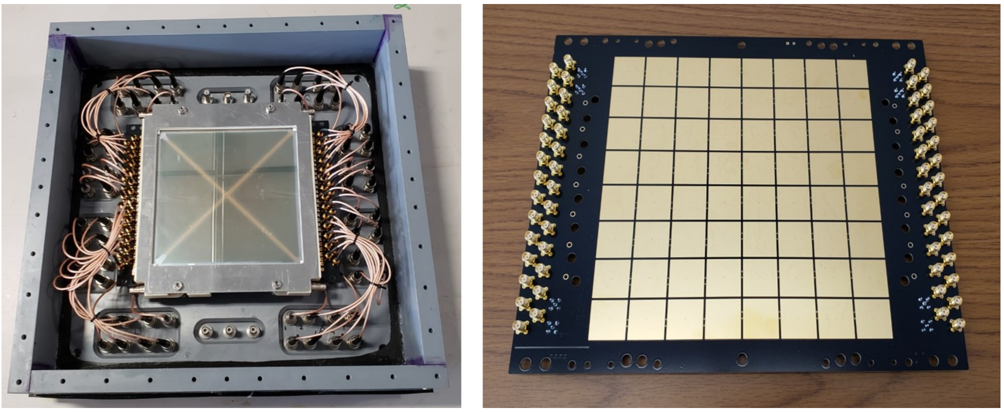

Figure 4: (left) Pixel GEN II-LAPPD coated with wavelength shifter was installed in housing ready for swapping with MaPMTs. (right) The 8×8 array 25×25 mm^2 pixel readout board attached behind the LAPPD, the pixel size is exactly the same size as a quadrant of MaPMT.

2.4 Electronic Readout Design and Bench test

For the three photosensors and electronic readout systems of the TCD, we have worked on the design and bench tested all of them. The simple sum readout board of the MaPMT was designed, produced and tested before installing it into the TCD. The MaPMT with MAROC sum readout was designed, produced and delivered to JLab just before the COVID-19 shutdown. We will continue its test when JLab reopens. And the LAPPD was designed, produced and tested. It is ready to be installed onto the TCD. The details are the following.

- MaPMT with simple sum readout

  The JLab Detector Group designed the simple sum board to read out four quadrants of one MaPMT with each summing 16 pixels. Then the 4 signals are also summed into one total sum which accounts for all 64 pixels. The 5 signals allow us to use one MAPMT with two levels of spacial resolution at the same time. With the help from the JLab fast electronic group, the Duke group carried out the test of a sample board for one MaPMT using a laser at a well maintained JLab test stand for MaPMT. The resulting sum of four quadrant signals matches the total sum signal and all signal shapes are good for Cherenkov readout. Then a larger assembly board was made to read out all 16 MaPMTs. It was tested with all 16 wavelength shifter coated MaPMTs model H12700-03 to confirm the performance before being installed into the housing box of the TCD.

- MaPMT with MAROC sum readout

  The MAROC electronics used in the CLAS12 RICH detector can read out each of the 64 pixels of an MaPMT and save the digitized information. It has three boards, namely an adapter, a MAROC, and an FPGA boards. The JLab fast electronic group and INFN Ferrara group helped design a sum board inserted between the MAROC and FPGA board to read out the four quadrants and the total sum, similar to what the simple sum board does. This allows three levels of spacial information of one MaPMT to be recorded simultaneously. The Duke group did the test on a sample board before the boards were produced in Italy under the INFN Ferrara group's guidance. The boards arrived at JLab in the middle of March 2020 just before the lab shutdown. We will continue the test once JLab reopens. The electronic housing box for the MaPMT with MAROC sum readout was designed by the Duke group and its fabrication will be finished once Duke University reopens.

- LAPPD with pixel readout

  New technology that has a high tolerance to the magnetic field is under consideration as an alternative for the photosensors of the SoLID Cherenkov counters. The MCP-

PMTs with pixel readout are developed at Argonne and Incom. We set up a 20 × 20 cm^2 GEN II-LAPPD loaner to be tested in the TCD. Argonne group had the GEN II-LAPPD attached to an 8 × 8 array 25 × 25 mm^2 pixel electronic board, which is exactly the same pixel size as the MaPMT quadrants for direct performance comparison. We coated the LAPPD with wavelength shifter for enhanced UV range Cherenkov photon detection and installed it in the LAPPD housing with all electronics connected. The LAPPD is ready to be swapped with MaPMTs for beamline testing once JLab reopens.

2.5 Installation, assembly, and cosmic testing in the ESB at Jefferson Lab

The following is a brief description of the work completed. Please see the appendix for a more detailed summary.

- The Cherenkov tank with two scintillator planes and 9 calorimeter modules were assembled in the ESB at Jefferson Lab. The detector package set up for bench tests with cosmics can be seen in Fig. 5.
- The MaPMTs were connected to the digital summing board and installed into the electronics housing box, before being attached to the Cherenkov tank. An image of the 16 tiled MaPMTs can be found in Fig. 6.
- All scintillator bars/PMTs were gain matched using a ^{60}Co source.
- The Cherenkov MaPMTs were gain matched initially using single-photoelectron traces on an oscilloscope, and later using random triggers once the installation in Hall C was complete.
- All calorimeter blocks/PMTs were gain matched with cosmics by forming coincidences with two scintillator bars placed under and above the calorimeter blocks to ensure the cosmic radiation fully traverses the length of the relevant block.
- Tests with cosmics of the entire detector package were performed to verify the DAQ configuration and to sanity check all the detector channels.

2.6 Installation in experimental Hall C and low rate data collection

The following is a brief description of work completed. Please see the appendix for a more detailed summary.

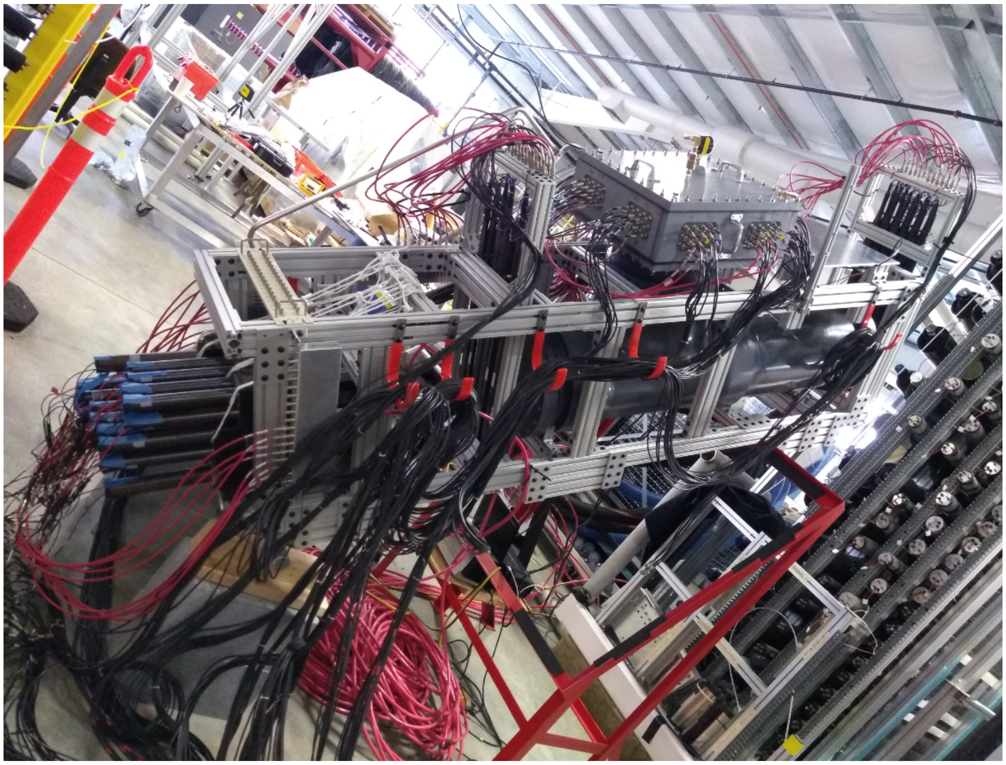

Figure 5: Picture of the Cherenkov test stand as assembled in the ESB building at Jefferson Lab.

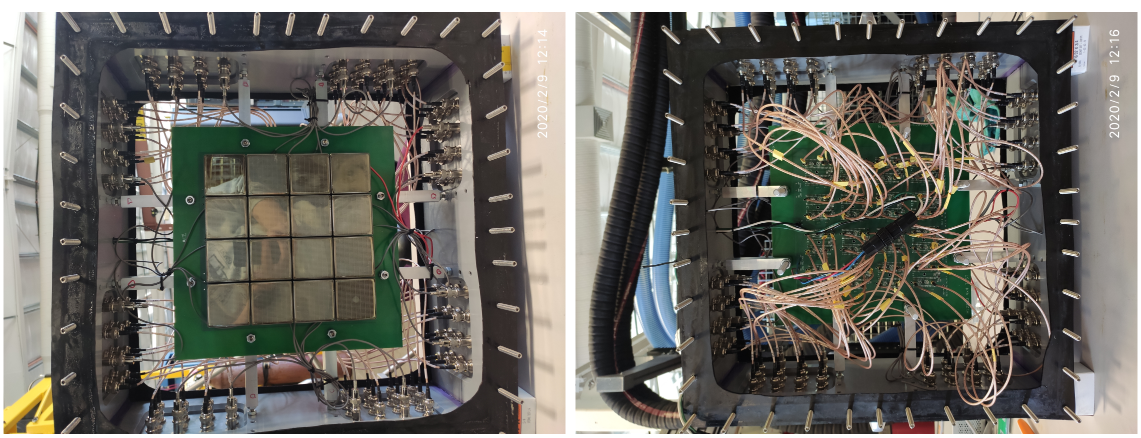

Figure 6: Picture of the Cherenkov MaPMT array with the simple sum readout.

- The detector package was secured onto the test stand designed at ANL and built at JLab. The device was then installed in the large-angle, low-rate configuration in Hall C on the Super High Momentum Spectrometer side, at 17 feet from the target and 75° angle w.r.t the beam line along the beam direction.

- The tank was filled with CO_2 gas at 0.3 psi above 1 atm.

- Before beam arrival into Hall C random trigger events were collected to refine the gain-matching of the MaPMTs. Gaussian fits to the charge integral distributions corresponding to single photo-electron signals were performed to obtain calibration coefficients that will convert charge integrals to number of photoelectrons for the beam data, see Fig. 7.

- Before the shutdown of operations at Jefferson Lab due to COVID-19, two days of beam data were collected with polarized ^{3}He and ^{12}C as targets and with the FADCs in both mode-1 and mode-3.

- The response from one representative MaPMT (the sum signal only, plots of quad signals per PMT are also available) is shown in Fig. 8 and Fig. 9. Similar plots for all 16 MaPMTs are shown in the Appendix. Preliminary analysis of the collected data shows detector response within expectations.

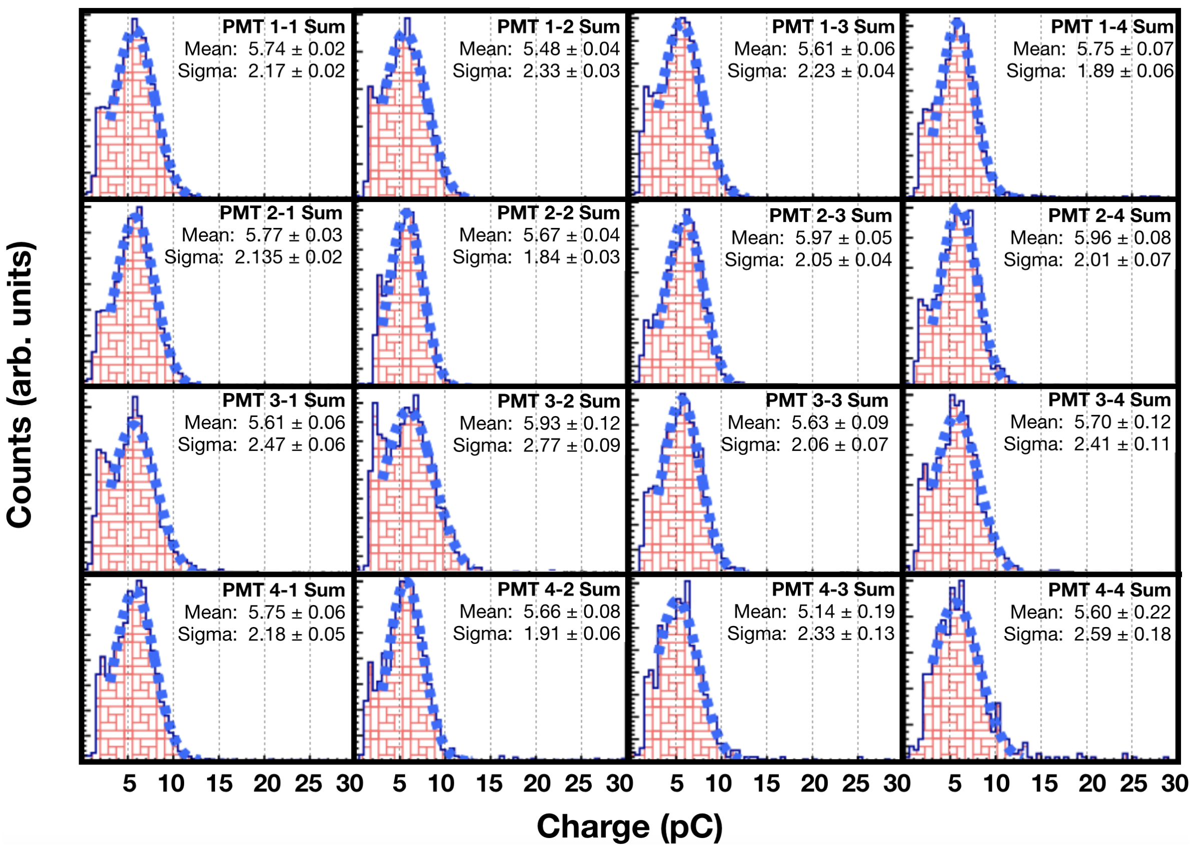

Figure 7: Plots of the integrated charge distribution per MaPMT (in pC) corresponding to one photoelectron (data taken with a random trigger).

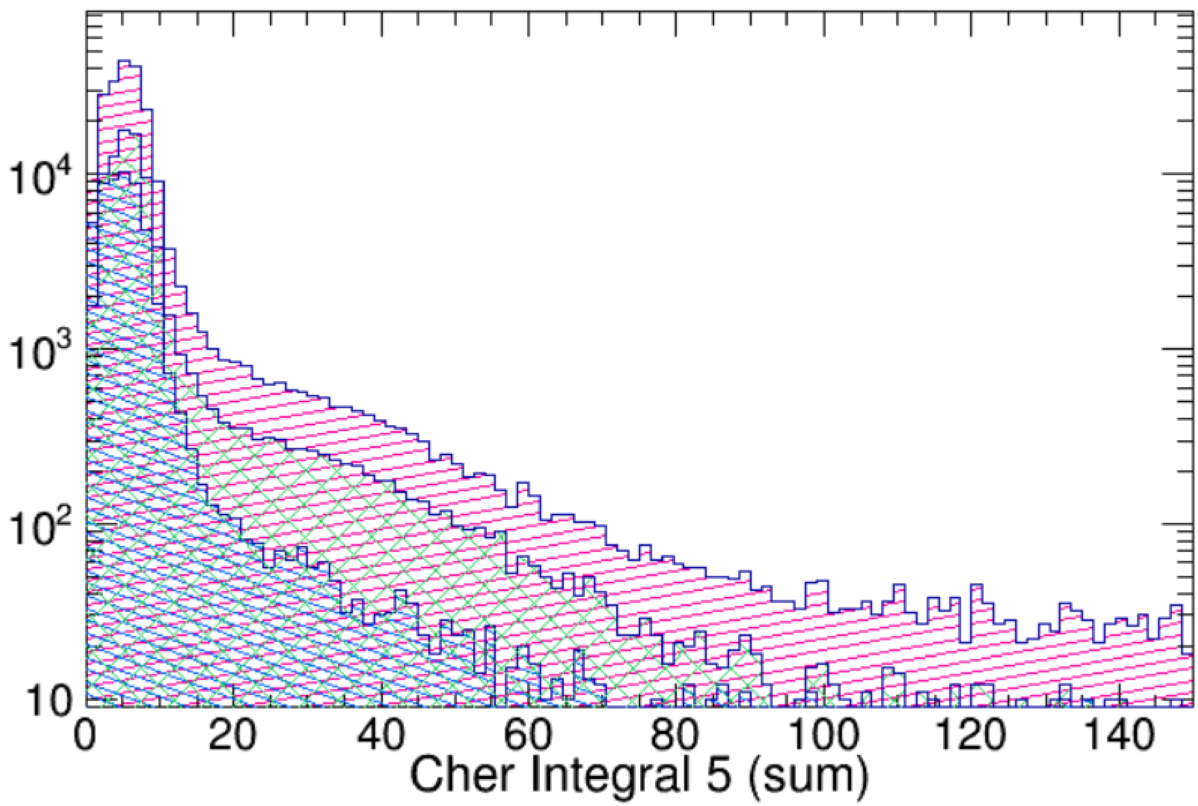

Figure 8: Beam data: charge integral in pC, FADC250s in mode 3. Here only one of the 16 MaPMTs is shown (sums signal only, plots of quad signals are also available but not shown). The charge integrals from all the other maPMTs are shown in the Appendix. Different histograms are obtained with different timing cuts as explained in the Appendix.

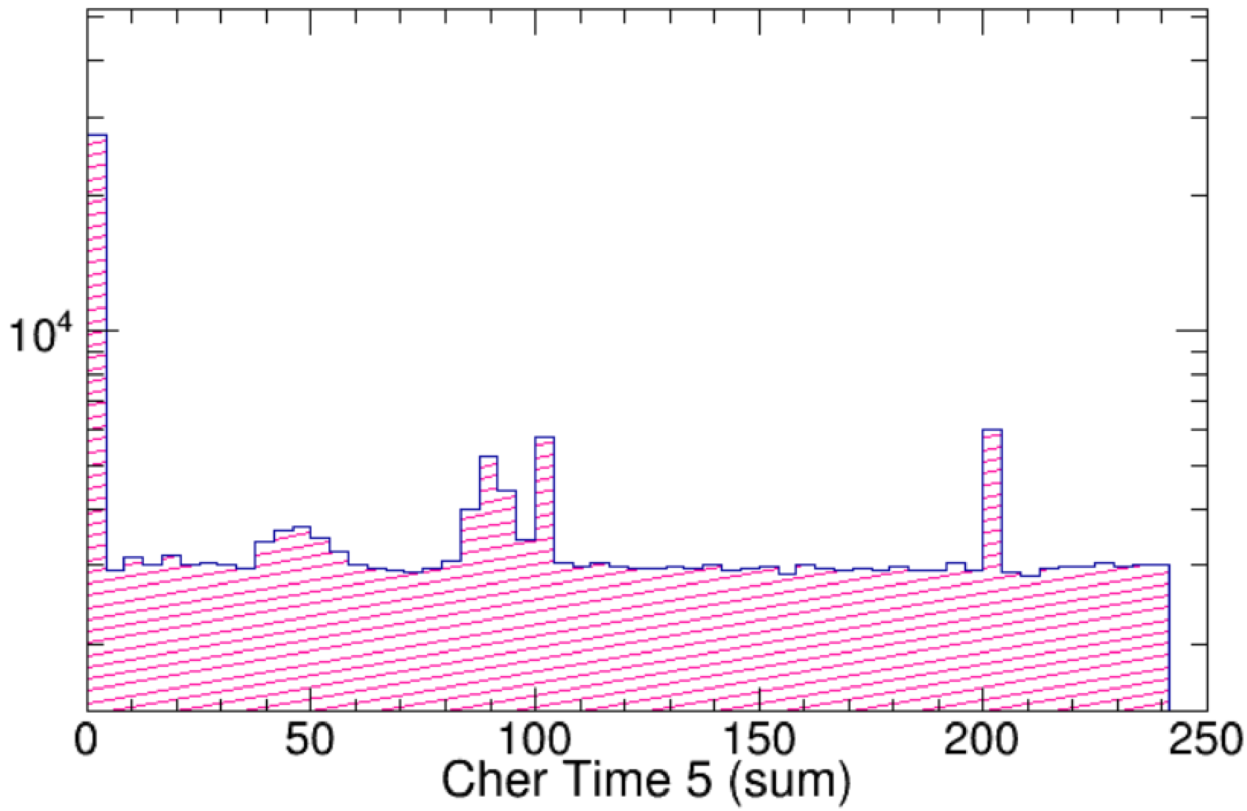

Figure 9: Beam data: timing distribution in ns, FADC250s in mode 3. Here only one of the 16 MaPMTs is shown (sums signal only, plots of quad signals are also available but not shown). The timing distributions from all the other maPMTs are shown in the Appendix.

A Appendix

A.1 Cosmics testing and installation into experimental hall

The detector package needed to test the Cherenkov prototype has been assembled at Jefferson Lab during the month of February 2020. Prior to the installation in Hall C the test was set up in one of the experimental buildings (ESB) at Jefferson Lab for cosmics testing. In what follows the cosmics test and the installation in Hall C will be discussed and preliminary results from the beam test will be shown.

A.1.1 Detector package assembly and cosmics tests prior to in beam testing

A picture of the detector package as installed in the ESB at Jefferson Lab for cosmics testing is shown in Fig. 5.

The detector package consists of two scintillator planes that flank the Cherenkov tank, 9 calorimeter blocks arranged in a 3x3 array right after the second scintillator plane at the back of the Cherenkov tank and the Cherenkov tank itself with a box placed at the top of the tank that contains the array of 16 multianode PMTs. Each multianode PMT has 5 signal outputs: one output corresponding to the sum over all 64 pixels and 4 additional outputs representing the sum over 16 pixels only (the so-called quad signals). A picture of the board with the 16 multianode PMT array that sits inside the box at the top of the Cherenkov tank is shown in Fig. 6 before the installation in the tank. The maPMTs have been gain matched initially (using an oscilloscope) by choosing the high voltage per PMT that gives rise to a single-photoelectron signal with an amplitude of 10 mV. Later on, once the test stand was installed in Hall C the maPMT gain matching has been refined by using a random trigger and fitting the FADC250 charge integral distributions (see next subsection).

Each scintillator plane is made of 11 plastic scintillator bars of about 1 inch width read at one end only by a 0.5 inch Hamamatsu PMT. There is roughly a 0.25 inch overlap between adjacent bars. Initially the scintillator bars have been gain matched with a 60Co source to show roughly the same amplitude on an oscilloscope from the signal induced by the photons emitted by the 60Co (around 200 mV). The source was placed at the opposite end of the bar w.r.t. the end that the PMT is attached to. An up-close picture of the scintillator planes before the installation in the detector stand is shown in Fig. 10. The main purpose of the scintillators was to provide rough tracking of the particles traversing the gas volume in the Cherenkov tank as well as to potentially help with the trigger.

The 9 calorimeter blocks were previously used in the HERA experiments and are of the Shashlyk type. A schematic of the type of blocks used taken from a HERA paper is shown in Fig. 11 while a real-life picture of the blocks used in this test is shown in Fig. 12. We used 2 different types of blocks: 4 blocks read by one PMT only (shown in the left-hand

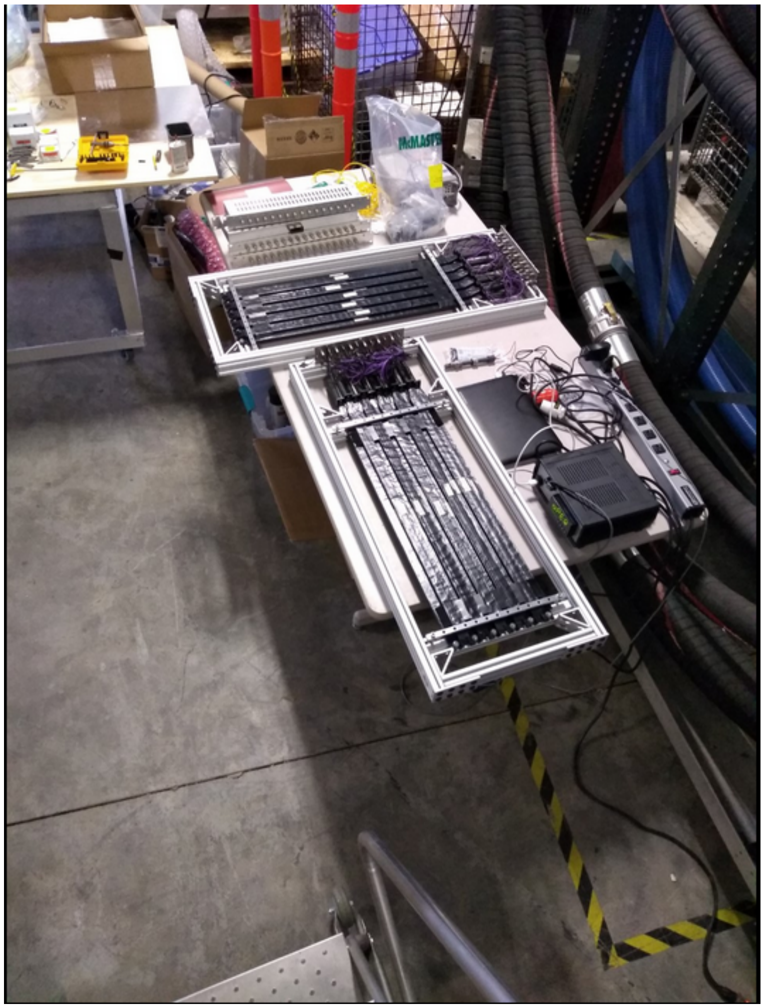

Figure 10: Picture of scintillator planes used in the detector package for the Cherenkov test. Each of the the 2 planes have 11 bars with a rough overlap between adjacent bars of about 0.25 inch. The scintillating light is collected at one end only by a 0.5 inch Hamamatsu PMTs.

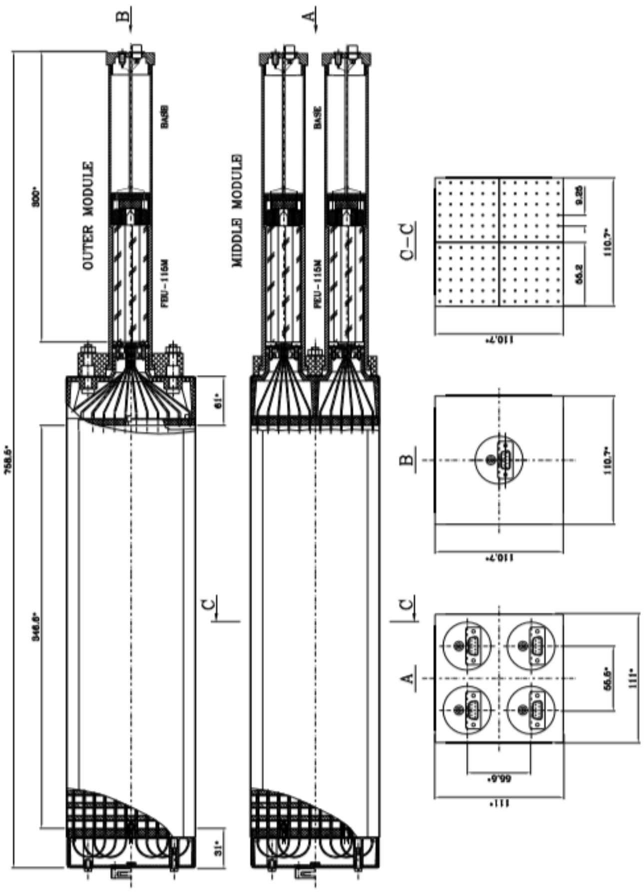

Figure 11: Schematic of the type of calorimeter blocks used in this test.

side of Fig. 11) and 5 blocks read by 4 PMTs each (shown in the right-hand side of Fig. 11). This put the calorimeter channel count at 24. The calorimeter blocks have been initially gain matched on the oscilloscope by triggering on the coincidence signal from two scintillator paddles placed on top and at the bottom of each calorimeter block to ensure that the particles from the cosmics rays traversed the entire length of the block.

For the cosmics test of the entire detector package as performed in the ESB the trigger consisted of a 3-fold coincidence between the 2 scintillator planes and the sum of the signals from all the calorimeter blocks. The detector channels were read by FADC250s. The Cherenkov tank was filled with a CO_2 gas at 0.3 psi above atmosphere. The whole detector package was placed at about 35 deg angle w.r.t. the horizontal to increase the rate of cosmics rays.

As an example, plots of the scintillator planes response to cosmics rays from data taken with the test setup in the ESB is shown in Fig. 13 and Fig. 14. The integrated charge per scintillator bar (in pC) is displayed where a FADC250 threshold per scintillator channel was used to emphasizes the minimum ionizing particles signal. From the mean of the inte-

Figure 12: Picture of the calorimeter blocks used in this test.

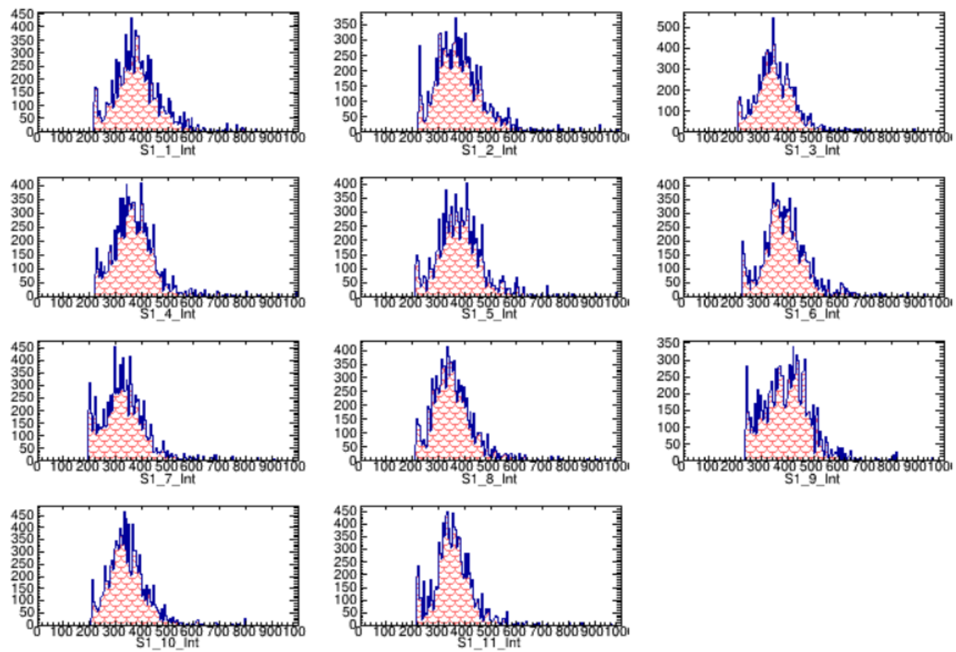

Figure 13: Plots of the integrated charge distribution per channel (in pC) in the first scintillator plane (the plane that is placed at the front of the Cherenkov tank).

grated charge distributions per scintillator channel it can be seen that the gain matching is acceptable.

A.1.2 Installation in Hall C and maPMT testing with a random trigger (no beam)

At the end of the second week of March the Cherenkov test stand has been installed in Hall C on the the side of the beam line where the Super-High Momentum Spectrometer (SHMS) resides. The rough angle at which the test stand is placed w.r.t. the beam line is 105 deg and the distance from the target of about 17 feet. The position of the test stand at this location was chosen such that the SHMS can still be rotated remotely for the data taking of the current experiment on the floor in Hall C (the "d_2^n" experiment). This should be our low-rate configuration. Before beam arrival into the hall a random trigger was used to take maPMT data to verify/refine the gain matching done with the oscilloscope. The final gain matching after few small high voltage adjustments is shown in Fig. 7 and Fig. 15. The mean from the Gaussian fit for each individual charge integral distribution coming from the single photoelectron signal becomes the calibration constant for in-beam data that will make the conversion from charge integral (in pC) to number of photoelectrons.

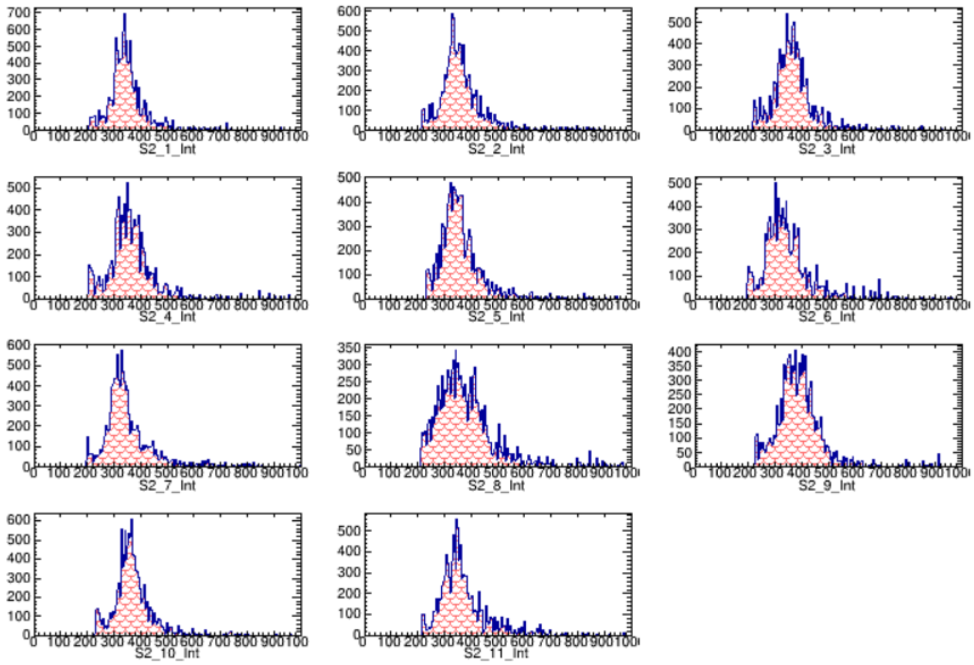

Figure 14: Plots of the integrated charge distribution per channel (in pC) in the second scintillator plane (the plane that is placed at the back of the Cherenkov tank).

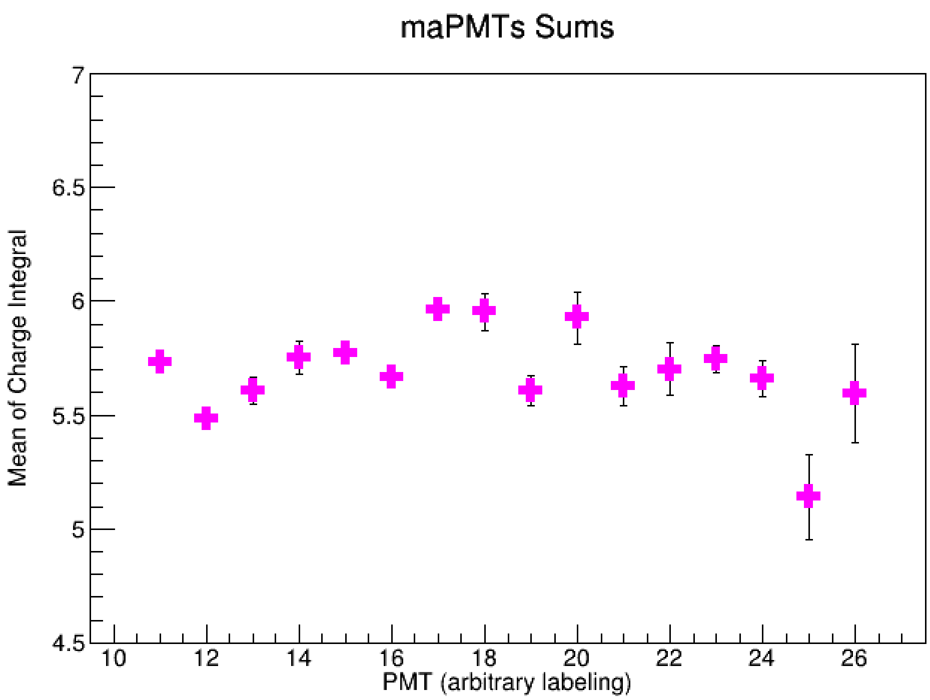

Figure 15: Mean from a Gaussian fit to the integrated charge distribution per maPMT (in pC) corresponding to one photoelectron (data taken with a random trigger).

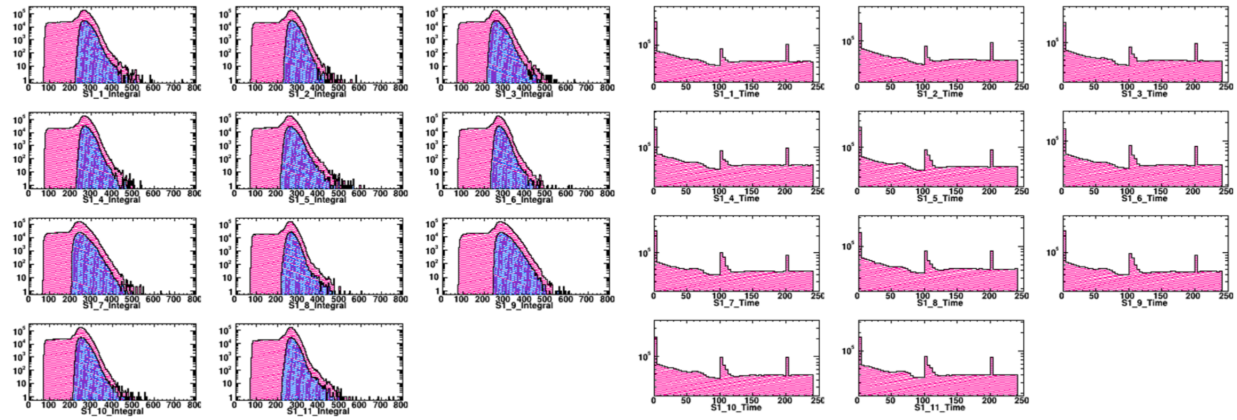

Figure 16: Beam data (FADC250s in mode 3) from the first scintillator plane. The charge integral in pC (left) and the timing distributions in ns (right) are shown. The two different distributions in the charge integral plot are obtained with different timing cuts.

A.2 In beam data taking and analysis

Before the shutdown of operations at Jefferson Lab due to COVID-19, Hall C got only 2 days of beam after the polarized 3He target installation for the startup of the "d2" experiment (during the "d2" target installation we installed the Cherenkov test stand). We have been taking data with the Cherenkov test stand for all that time on a C target and on the polarized 3He target with the FADC250s in mode 3 (identification up to 3 pulses per event per channel with pulse time and pulse integral available in the data stream) and in mode 1 (pulse shapes available). The beam data analysis is still ongoing but here we present few preliminary findings from a subset of the mode 3 data we took. The first scintillator plane appears to have been overwhelmed by hits during the in-beam data taking as shown in Fig. 16. There is a peak barely visible in the timing distribution at 70 ns that's in time with a good coincidence between the calorimeter and the second scintillator plane as seen in Fig. 16. but that signal is pretty much buried under a significant background. The pulse shape data that we took with FADC250s in mode 1 are now under analysis and should provide more insight into the response of this detector to beam. The second scintillator plane clearly showed signals from minimum ionizing particles as seen in Fig. 17. In the end we used a 2-fold coincidence between the second scintillator plane and the calorimeter for our golden runs. Plots of the calorimeter timing distributions as well as distributions of the charge integral per channel are shown in Fig. 18.

The response from all the maPMTs (the sum signal only, plots of quad signals per PMT are also available) is shown in Fig. 19 and Fig. 20. The 3 different distributions shown are obtained with different timing cuts. The histogram depicted in blue was obtained using a timing cut that selects pulses that come at a random time w.r.t. the trigger so that the

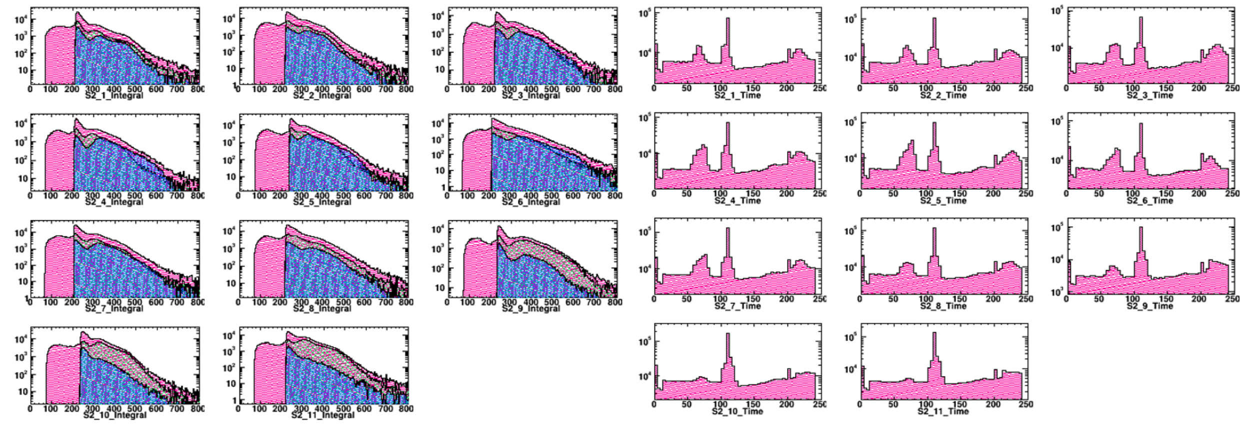

Figure 17: Beam data (FADC250s in mode 3) from the second scintillator plane. The charge integral in pC (left) and the timing distributions in ns (right) are shown. The two different distributions in the charge integral plot are obtained with different timing cuts.

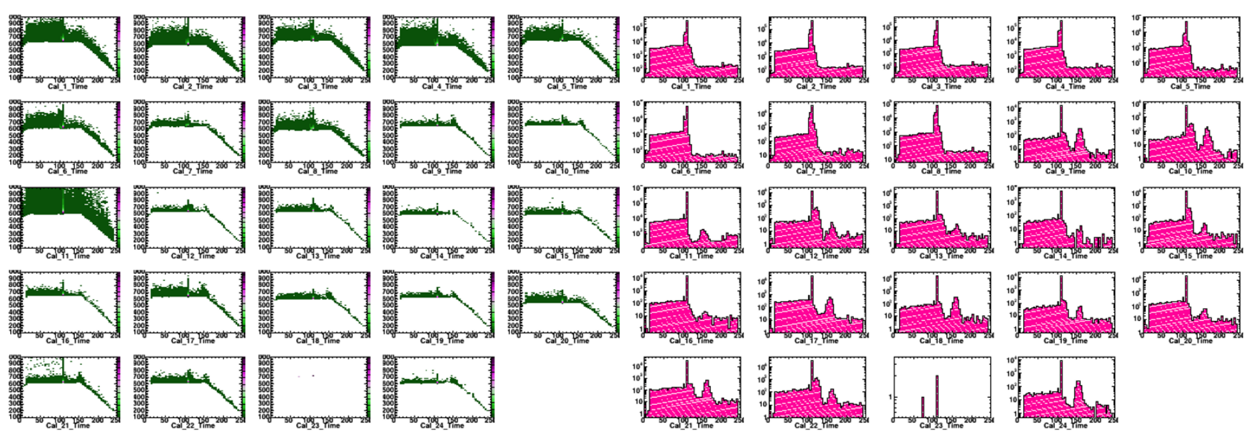

Figure 18: Beam data (FADC250s in mode 3) from the calorimeter. The charge integral in pC vs pulse time (left) and the timing distributions in ns (right) are shown per calorimeter channel.

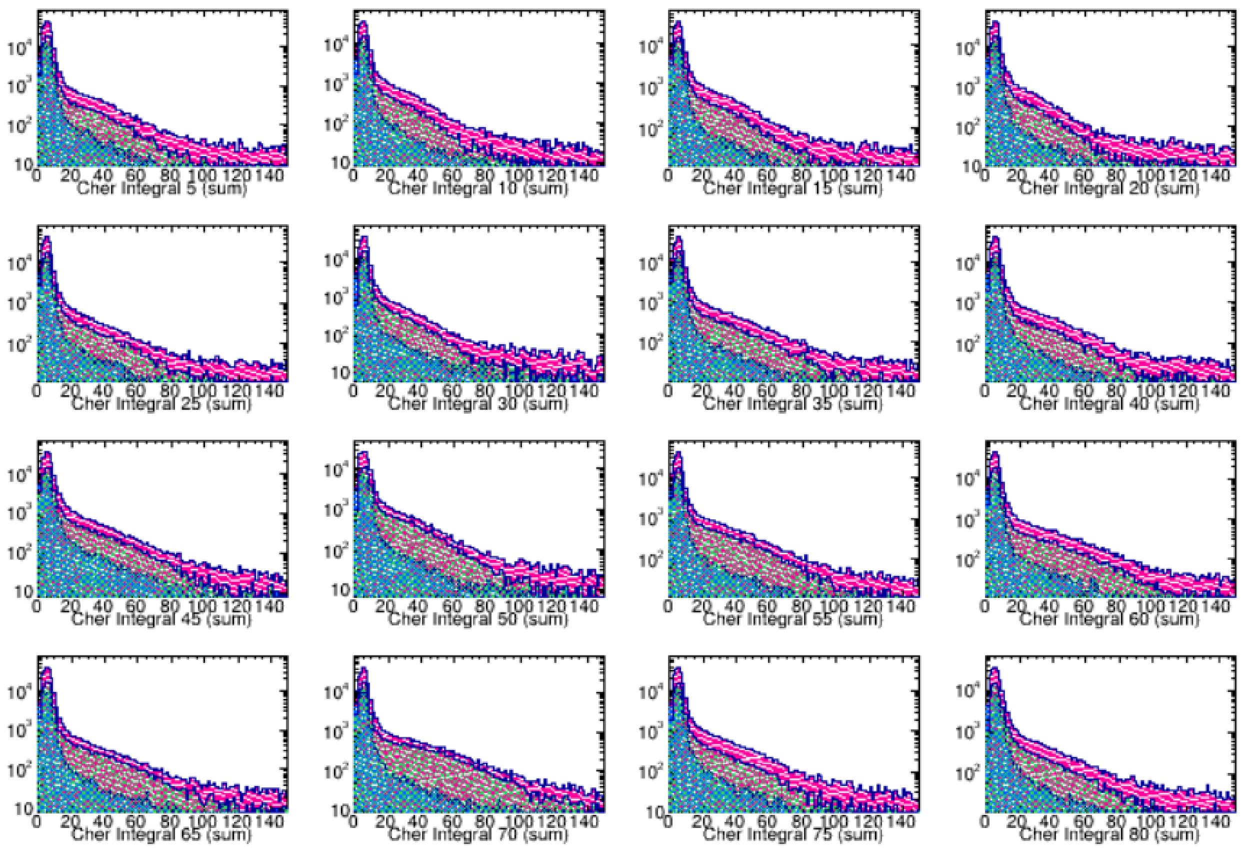

Figure 19: Beam data: charge integral in pC (FADC250s in mode 3) from all 16 MaPMTs (sums signal only, plots of quad signals are also available but not shown). Different histograms are obtained with different timing cuts as explained in the text.

single photoelectron signal is emphasized. The distributions depicted in green were obtained with a timing cut that includes the signal from particles that come in time with the trigger. The analysis of the mode 3 data is not final yet but looks indeed very promising. We see an average of roughly 7 to 9 photoelectrons from each individual maPMT when using CO2 at 0.3 psi above atmosphere. The plan going forward is to finalize the analysis of the mode 3 and mode 1 data we took on a 12C and ^{3}He target with the maPMTs as photon detector and resume in beam testing once operations in Hall C are resumed.

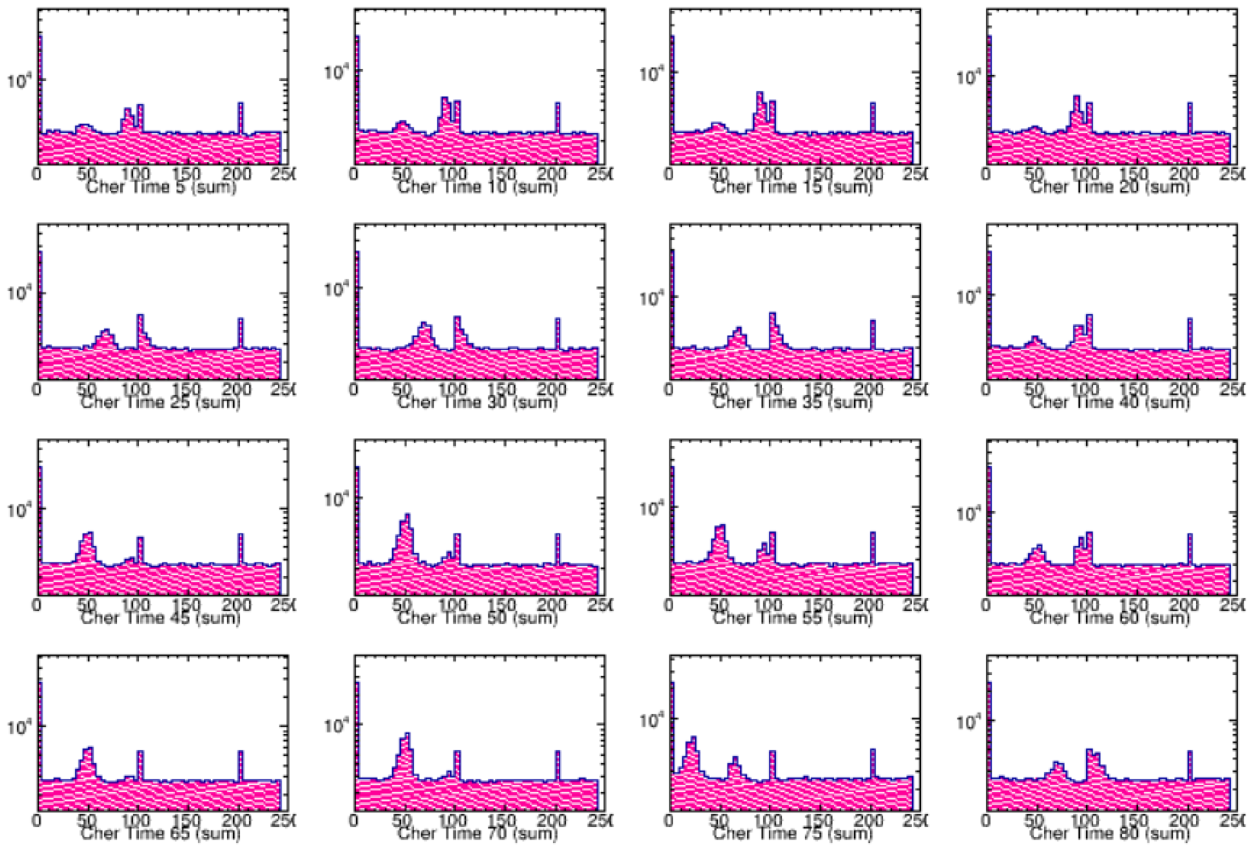

Figure 20: Beam data: timing distribution in ns (FADC250s in mode 3) from all 16 MaPMTs (sums signal only, plots of quad signals are also available but not shown).